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Alternative Methods for Disposal of Low-Level Radioactive Wastes

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Task 2c: Technical Requirements for Earth Mounded Concrete Bunker Disposal of Low-Level Radioactive Waste

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Prepared for
U.S. Nuclear Regulatory
Commission

2C

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ABSTRACT

Current practice in the US for disposal of commercial low-level radioactive wastes (LLW) is burial in shallow trenches. In 1983, approximately 110,000 cubic meters of these wastes were disposed of at the three operating commercial sites. Three additional sites have ceased operations in the past decade and are awaiting technical and institutional determinations that will allow for final closure. Although shallow land burial in trenches may continue to be practiced, it is likely that techniques for engineered disposal other than shallow land burial will be introduced to the NRC or states for licensing consideration within the next few years.

The earth mounded concrete bunker (EMCB) alternative is one method that may be proposed. The name for this alternative was coined to describe the disposal method used in France at the Centre de la Manche. Consequently, this alternative was narrowly defined by the French disposal practices in which waste packages are buried in concrete-filled trenches (concrete bunkers) and then waste packages are stacked over this bunker and covered with an earth mound.

However, variations of this method are certainly possible and could lead to enhanced performance in some cases.

Some improvements are recommended in this report, including the use of pervious backfill around the belowground monoliths, and extending the low permeability surface layer beyond the limits of the monolith to the surface drainage ditches. These features should act together to minimize infiltration and allow water that does infiltrate to quickly drain away from the disposal units to monitored collection systems.

The experience gained with this method at the Centre de la Manche is described, including unit operations and features and components. The method has been used in France since 1969 and has been improved over the years as experience was gained. This short-term experience indicates the method can be a safe, effective means of meeting the performance objectives for disposal of LLW specified in 10 CFR Part 61 Subpart C.

The existing criteria developed for near-surface disposal (10 CFR Part 61, Subpart D) were assessed for applicability to the EMCB alternative in Task 1 (Bennett and others, 1984) and were reassessed in Task 2, as reported herein. With minor qualifications, these criteria were found to be applicable to the evaluation of this alternative in the reassessment. These conclusions differ slightly from the Task 1 findings. These differences are explained in the text. In most cases, the authors concluded that the exceptions to the criteria or special cases noted in Task 1 could be handled through the issuance of guidance and evaluated within the framework of the existing criteria.

Additional technical considerations that should be addressed are recommended. As mentioned above, some of these considerations may be addressed through

guidance within the context of the existing criteria. Other issues may require supplemental criteria to be properly evaluated. The issues are listed below:

In the discussion of site suitability criterion 61.50 (a)(7), it is pointed out that the possible exception for disposal below the water table is not applicable to the EMCB alternative. Because EMCB's are constructed both above and below grade, it would not be possible to place some wastes below the water table without placing other wastes within the zone of fluctuation.

Supplemental technical issues not addressed by existing site suitability criteria that are recommended for evaluation of site suitability include the existence and potential adverse effects of dispersive soils, liquefiable soils, corrosive soils, expansive soils, karst areas, and areas undergoing land subsidence. The potential problems caused by occurrence of such deposits are discussed herein.

In the reassessment of design criteria, the need to assess the chemical compatibility of construction materials, waste form, and site soils was pointed out as an additional consideration.

In addition the need to plan for individual disposal unit closure, as well as site closure was mentioned in the reassessment of operations and closure criteria.

The need to plan for temporary closure of active disposal units was noted. The need to consider the potential for damage to the engineered disposal unit from the contained wastes through chemical attack, for example, was pointed out.

The monitoring issues raised for consideration include the need to monitor individual disposal units and establish reporting procedures, and to provide a disposal plan for sampled soil, water, and construction materials, if contaminated by radioactivity.

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Mr. James Shaffner was the NRC technical monitor. His advice and support are greatly appreciated. Mr. David Bennett was principal investigator and coauthor of this report, with Mr. W. O. Miller.

The work was performed under the general supervision of Mr. J. S. Huie, Chief, Rock Mechanics Application Group (RMAG), Engineering Geology and Rock Mechanics Division (EGRMD), Geotechnical Laboratory (GL) and Dr. Don C. Banks, Chief, EGRMD.

Dr. William F. Marcuson III was Chief of the Geotechnical Laboratory during this study.

Mr. Fred Brown was Technical Director of WES. COL Robert C. Lee was Commander and Director of WES during this study.

1. INTRODUCTION

1.1 Background

The Atomic Energy Act of 1954 and the Energy Reorganization Act of 1974 gave the US Nuclear Regulatory Commission (NRC) the responsibility for assuring and maintaining public health and safety as may be affected by commercial nuclear facilities, including facilities for the disposal of low level radioactive waste (LLW).

The National Low Level Radioactive Waste Policy Act of 1980 (Public Law 96-573) gave the individual states responsibility for the management and safe disposal of all commercial LLW generated within their borders. The act provides, subject to congressional approval, that each state may enter into regional compacts with neighboring states to establish and operate regional disposal sites.

The NRC has established uniform procedures for licensing and regulating the disposal of LLW. The procedures are set forth in the Code of Federal Regulations 10 CFR Part 61. Subpart D and related regulatory guidance provide specific technical criteria for land disposal. Specific sections of subpart D provide technical criteria related to siting, design, operations, and closure of a near-surface disposal facility. Subsections were reserved for methods other than near-surface disposal.

Current practice is to dispose of commercial LLW by burial in shallow trenches. In 1983 approximately 110,000 cubic meters of these wastes were disposed of at the three commercially operated disposal facilities. Waste disposal at three additional sites has ceased in the past decade and these sites are awaiting permanent closure.

Although shallow land burial in trenches may continue to be practiced, it is likely that other techniques for engineered disposal may be submitted to the NRC or the states for licensing consideration within the next few years. It is important that the NRC establish uniform criteria, or guidance, by which engineered facilities may be evaluated and that such criteria or guidance be compatible with the performance objectives set forth in 10 CFR Part 61 Subpart C.

1.2 Purpose and Scope

The overall purpose of this study was to ensure that the criteria contained in 10 CFR Part 61 (61.50-61.53) or guidance as required to completely evaluate 5 alternative methods of LLW disposal were available to NRC and the states. The methods considered in this study were aboveground vaults, belowground vaults, earth mounded concrete bunkers, mined cavities, and shafts. Criteria or guidance related to site suitability, design, operations, closure, and monitoring were to be assessed. Where judged to be appropriate, recommendations were to be made to modify existing criteria and to address additional technical issues. Guidance related to the implementation of criteria for acceptable waste forms and classes that would be appropriate for disposal in specific engineered facilities are also important areas of consideration. However, development of guidance for acceptable waste forms or waste classifications was beyond the scope of this study.

Development of conceptual designs were also not within the scope of this study. However, important features of the various alternatives were illustrated and discussed as they pertain to the satisfaction of the performance objectives. Although segregation of wastes prior to disposal in engineered facilities may be desirable for economic or political reasons, segregation has not been assumed as a requirement for this study.

Cost estimates were not prepared or reported for any of these alternative methods. It is recognized that guidance on conceptual designs and acceptable waste forms and classes appropriate for disposal using these alternatives would be useful to the states or individuals considering them, and that detailed costs would be an important consideration in their adoption. However, the most important issues are whether these methods can meet the performance objectives of Subpart C and how their performance can be judged.

The study was divided into 3 main tasks. Previous work was described in the task 1 report (Bennett and others, 1984), and included descriptions of all 5 alternatives, summaries of the experience with each method, and an initial assessment of the applicability of existing technical criteria relating to site suitability, design, operations, closure, and monitoring.

This report, one of a series, contains the results of subtask 2c of the investigation. Separate reports were prepared for each method investigated. The reports pertaining to the aboveground vault, belowground vault, earth mounded concete bunkers, and shaft disposal methods were each issued as one of a series of 4. Although each of these methods has some contrasts with existing shallow land burial practice, they are similar in many respects to existing near-surface disposal methods.

However, the mined cavity disposal alternative is quite different from existing near surface disposal practice. Consequently, during the course of the study, the NRC decided to deal with this method separately from the others.

1.3 Organization

Each of the task 2 reports has been organized in parallel format as described below.

Each report shares a common introductory section. In Part 2, the performance objectives are listed, the experience with the disposal alternative is summarized and updated, the unit operations and features and components of the particular alternative disposal facility are described, and the performance capabilities are summarized.

The technical criteria recommendations are developed in Part 3. The criteria are reassessed one by one, drawing from the assessment and conclusions made in the Task 1 report. The organizational scheme used is to list each criterion as it appears in 10 CFR 61, and discuss its objective and relevance to this disposal method. Next a recommendation is made to:

a. Retain the criterion as is.

b. Not apply the criterion in the evaluation of the particular alternative as it is inapplicable.

c. Modify the criterion to make it applicable to the particular alternative.

Any recommended modifications to existing criteria are underlined. Any departures or changes from the positions taken in the Task 1 report are noted and explained. This procedure is followed for each criterion.

At the end of each criteria section, i.e. site suitability, design, etc., suggested additional technical considerations that should be addressed are discussed. These considerations may form the basis for additional criteria, if judged to be necessary and correct by the NRC. Specific supplemental criteria are not given in prescriptive language. Rather, the issues that should be addressed and the reasoning behind them are stated. This method of presentation is thought to be more appropriate than offering specific criteria, as it allows the NRC to consider those issues and develop specific wording that it considers appropriate on a point by point basis. Alternatively, the NRC may wish to provide guidance without changes or additions to existing criteria.

In Part 4, conclusions and recommendations are offered on the feasibility of the disposal concept, the modified criteria and supplemental considerations, and on unresolved issues and research required to resolve them.

All references are listed after the body of the report. A glossary of major terms follows the references.

Because concrete is likely to play an important role in engineered disposal facilities, factors that impair long term durability of concrete and design and construction practices that can be used to minimize adverse impacts are discussed in Appendix A.

2. THE EARTH MOUNDED CONCRETE BUNKER DISPOSAL ALTERNATIVE

In the following paragraphs, the earth mounded concrete bunker (EMCB) alternative is described, including major components or features of the method, the experience gained with its use is summarized, and performance capabilities are discussed.

It should be noted that for any method to be considered by the NRC for licensing for disposal of low-level radioactive wastes, it must be capable of satisfying the performance objectives of 10 CFR Part 61 Subpart C (paragraphs 61.40 through 61.44). These performance objectives are listed below.

The discussion of performance capabilities at the end of this section is directed toward satisfaction of these performance objectives.

2.1 Performance Objectives

Paragraph 61.40 - "General requirement. Land disposal facilities must be sited, designed, operated, closed, and controlled after closure so that reasonable assurance exists that exposures to humans are within the limits established in the performance objectives in paragraphs 61.41 through 61.44."

Paragraph 61.41 - "Protection of the general population from releases of radioactivity. Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable."

Paragraph 61.42 - "Protection of individuals from inadvertent intrusion. Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed."

Paragraph 61.43 - "Protection of individuals during operations. Operations at the land disposal facility must be conducted in compliance with the standards for radiation protection set out in Part 20 of this chapter, except for releases of radioactivity in effluents from the land disposal facility, which shall be governed by Paragraph 61.41 of this part. Every reasonable effort shall be made to maintain radiation exposures as low as is reasonably achievable."

Paragraph 61.44 - "Stability of the disposal site after closure. The disposal facility must be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate to the extent practicable the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required."

2.2 Experience with the Method

The development of the earth mounded concrete bunker (EMCB) concept for disposal of radioactive wastes has been an evolutionary process. The use of earth shields for protection from radiation began with the design and construction of bomb shelters in the 1940's. The development of engineered structures and packages for containment of radioactive materials has continued with the increased acceptance and use of nuclear energy and radioactive materials in industrial processes and commercial products. The design of EMCB's includes features of trenches, belowground vaults, and earth mounds, as well as controlled packaging and encapsulation.

EMCB's for the disposal of low-level and intermediate-level wastes were first put in use in France in the 1960's (van Kote, 1982).

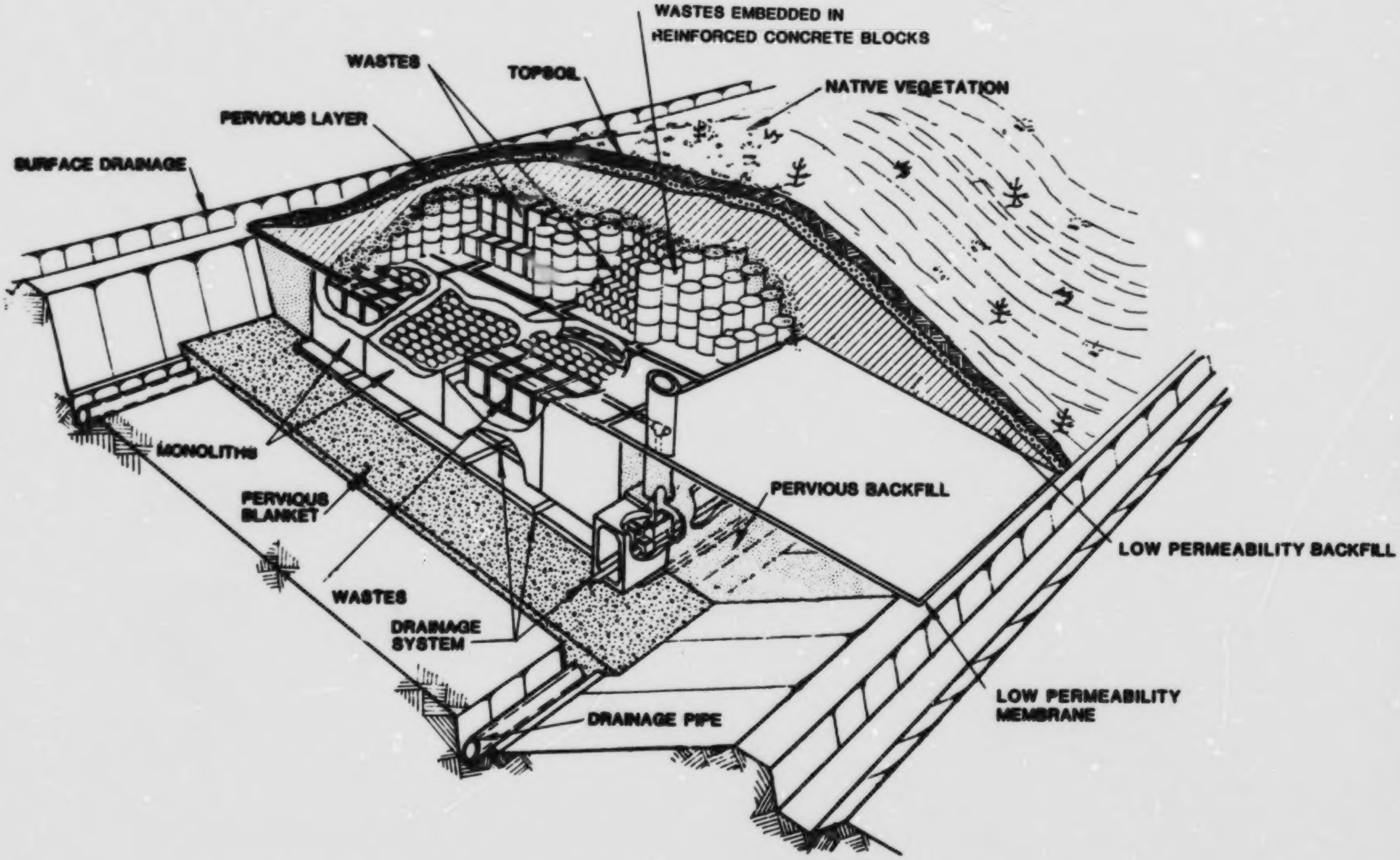
The basic design of the French EMCB's requires segregation of wastes according to level of activity. Intermediate-level wastes are embedded in concrete monoliths belowground; and low-level wastes, or intermediate-level wastes with appropriate packaging, are stored aboveground in earthen mounds (tumuli) over the concrete monoliths. Figure 1 is a perspective view of an earth mounded concrete bunker. Figure 2 is an exploded view of the construction phases of an EMCB.

Between 1969 and 1982, a total of over 170,000 m^3 of waste has been disposed in the Centre de la Manche facilities (Lavie and Barthoux, 1982). This volume represents about one-half the capacity of the facility. The waste volume received per year has steadily increased during the facility's operating life. It is estimated that remaining dispoal space at the site will accommodate about 5 years waste production, so a new site will be needed soon. It is projected (van Kote, 1982) that over 800,000 m^3 of the low- and intermediate-level wastes will be generated in France by the year 2000.

Since the EMCB alternative is a "hybrid" concept involving aboveground and belowground construction, encapsulation, and backfilling, with both concrete and earth, many variations have been suggested. For example, to reduce operating problems during cold or rainy weather, and to reduce subsequent drainage problems within the structure, it has been proposed (Feraday, 1982) that an air supported weather shield be installed over the facilities during filling (Figure 3). Such a concept has potential application to any LLW disposal method.

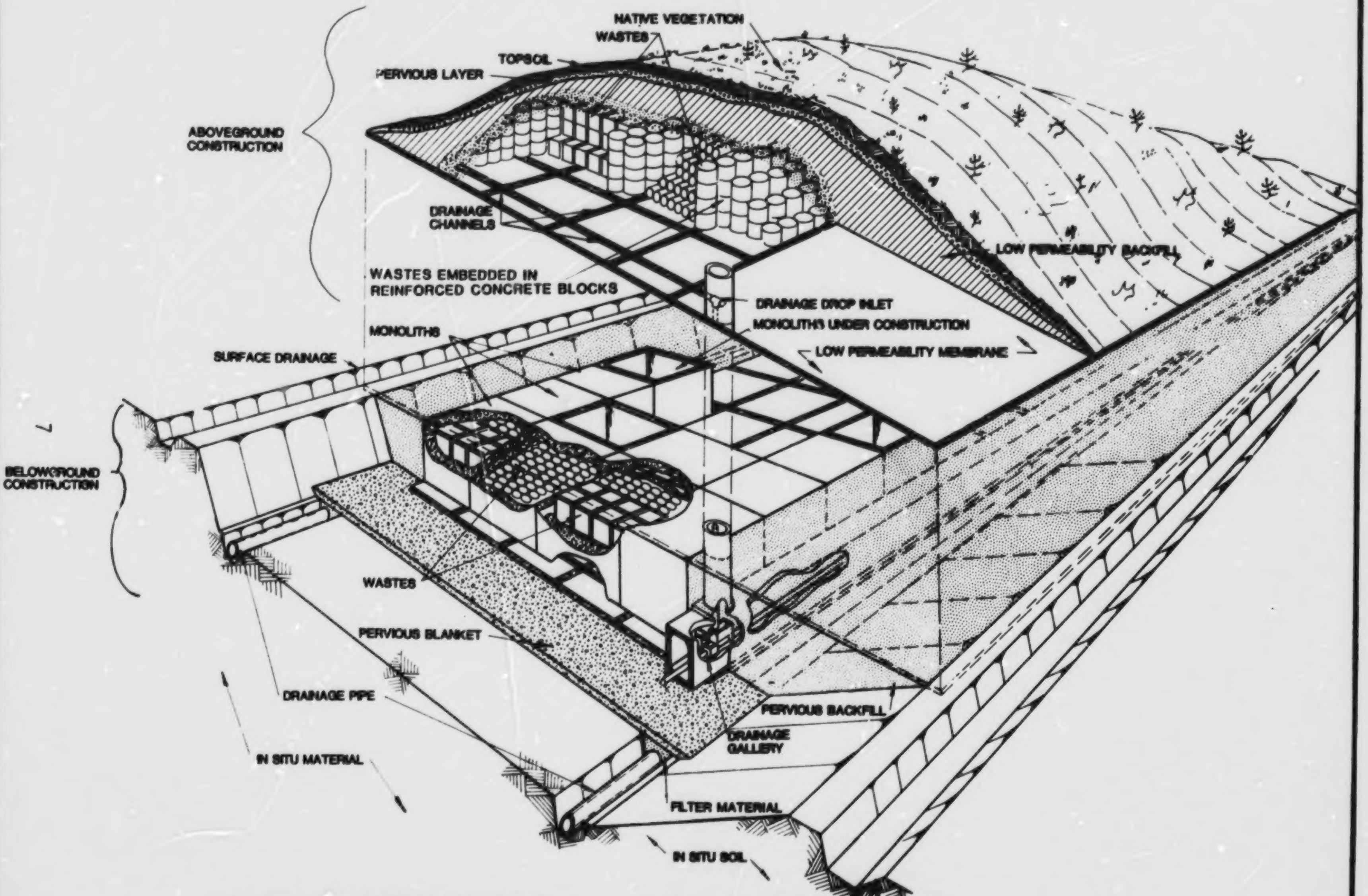
A variation of the EMCB concept has been tested by the Energy Research and Development Adminstration (ERDA) for the disposal of transuranic-bearing solid waste (Gilmore, 1977). The ERDA concept places steel drums containing wastes within trenches which are subsequently backfilled to form an earth mound (Figures 4 and 5).

Another variation of the bunker concept has been used for LLW storage in Ontario, Canada, at the Chalk River National Laboratory (CRNL) and at Whiteshell Nuclear Research Establishment (WNRE) in Manitoba, Canada (Feraday, 1982 & 1983; Charlesworth and Carter, 1982; and Morrison, 1974). The structures at each of these sites have evolved over the years from


WASTES EMBEDDED IN
REINFORCED CONCRETE BLOCKS
WASTES
TOPSOIL
NATIVE VEGETATION
PERVIOUS LAYER
SURFACE DRAINAGE
MONOLITHS
PERVIOUS BLANKET
PERVIOUS BACKFILL
LOW PERMEABILITY BACKFILL
WASTES
DRAINAGE SYSTEM
LOW PERMEABILITY MEMBRANE
DRAINAGE PIPE

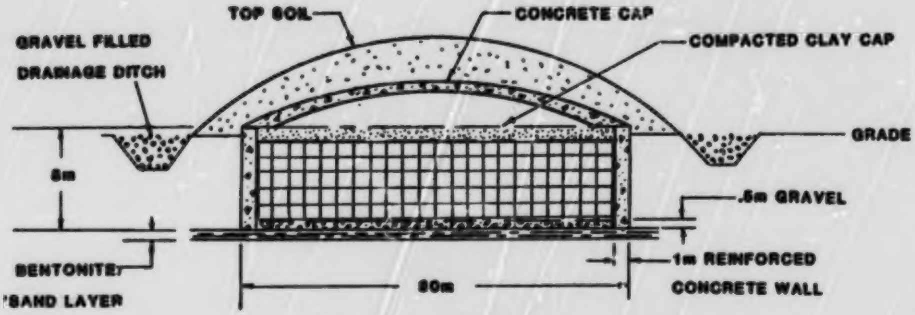
A perspective view of the Earth Mounded Concrete Bunker depicts the wastes which are separated according to level of activity. A drainage network is provided within and around the structure to prevent the contact of water with the wastes and to provide collection and monitoring capabilities.

Figure 1. Perspective view of an Earth Mounded Concrete Bunker. Source: modified from F. Van Kote, "Twelve Years Experience in Low-and Intermediate-Level Waste Disposal."

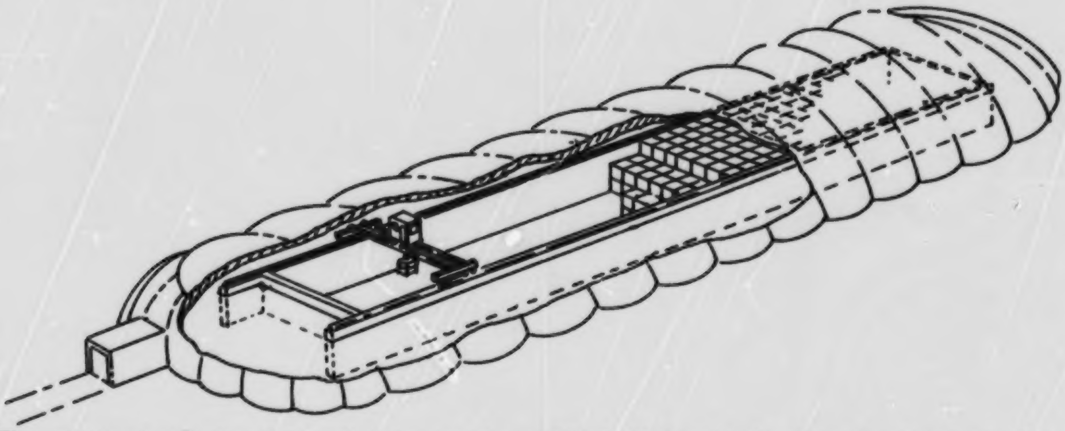

NATIVE VEGETATION
WASTES
TOPSOIL
PERVIOUS LAYER
ABOVEGROUND CONSTRUCTION
DRAINAGE CHANNELS
LOW PERMEABILITY BACKFILL
WASTES EMBEDDED IN REINFORCED CONCRETE BLOCKS
DRAINAGE DROP INLET
MONOLITHS UNDER CONSTRUCTION
MONOLITHS
LOW PERMEABILITY MEMBRANE
SURFACE DRAINAGE
BELOWGROUND CONSTRUCTION
WASTES
PERVIOUS BLANKET
DRAINAGE PIPE
PERVIOUS BACKFILL
DRAINAGE GALLERY
IN SITU MATERIAL
FILTER MATERIAL
IN SITU SOIL

Construction of an Earth Mounded Concrete Bunker involves a belowground phase and an aboveground phase. Wastes are embedded in concrete monoliths belowground. After filling the entire trench with monoliths, the trench is backfilled and sealed. Wastes are subsequently placed over the sealed monoliths and backfilled to ultimately create the aboveground mound.

Figure 2. Exploded view of the construction phases of an Earth Mounded Concrete Bunker. Source: modified from F. Van Kote, "Twelve Years Experience in Low-and Intermediate-Level Waste Disposal."

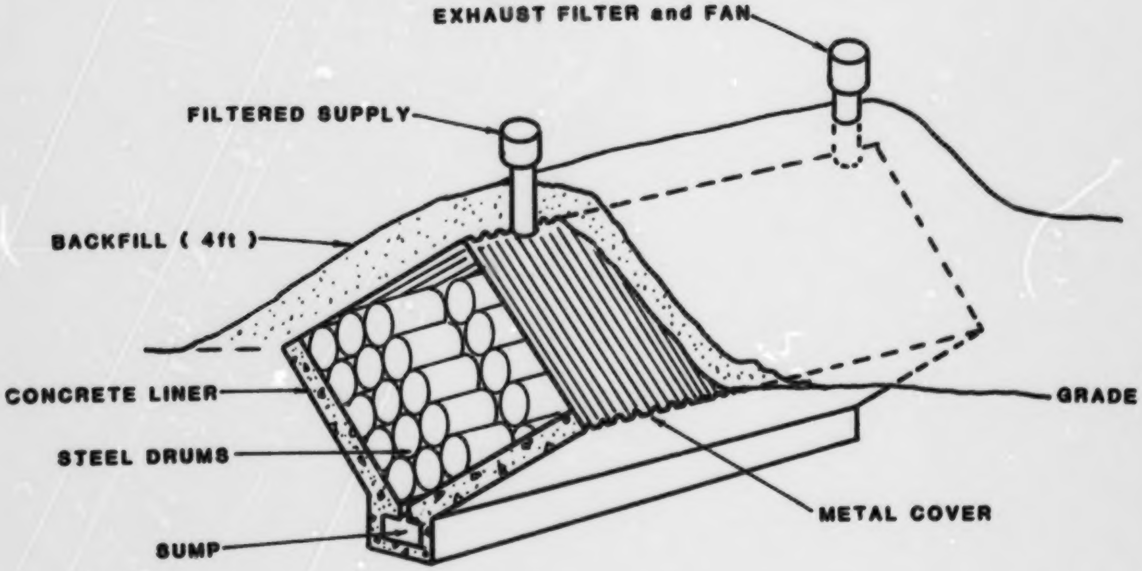

TOP SOIL
CONCRETE CAP
GRAVEL FILLED DRAINAGE DITCH
COMPACTED CLAY CAP
GRADE
8m
.5m GRAVEL
1m REINFORCED CONCRETE WALL
BENTONITE/SAND LAYER
30m

TYPICAL CROSS-SECTION
thru
FACILITY AFTER CLOSURE



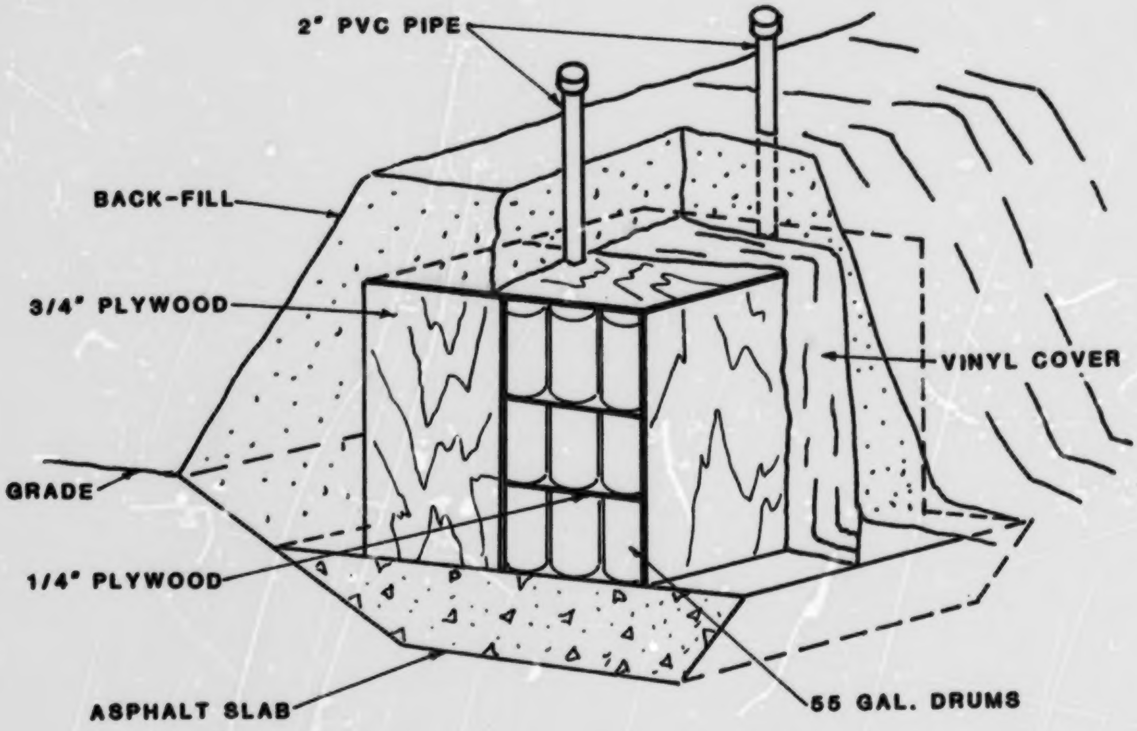
The conceptual drawing of a concrete walled disposal bunker depicts an air supported weather shield which is used during the operational stage. The facility represents only one of many possible variations of the Earth Mounded Concrete Bunker concept. The use of an air supported weather shield has potential application to most of the alternative disposal methods.

Figure 3. Variation of an Earth Mounded Concrete Bunker with an air supported weather shield. Source: modified from M. A. Feraday, "Canadian Experience with the Storage and Disposal of Low- and Intermediate-Level Waste," pp 411-429 in Proceedings of the Symposium on Low-Level Waste Disposal, Washington, D.C., 1982.


EXHAUST FILTER and FAN
FILTERED SUPPLY
BACKFILL (4ft)
CONCRETE LINER
STEEL DRUMS
SUMP
GRADE
METAL COVER

This variation of the Earth Mounded Concrete Bunker concept has been tested by the Energy Research and Development Administration. Steel drums containing transuranic wastes were placed in concrete lined trenches which were subsequently covered and then backfilled with earth.

Figure 4. Concrete-lined trench variation of the Earth Mounded Concrete Bunker concept. Source: modified from W. R. Gilmore, Radioactive Waste Disposal, Low and High Level, p. 273, Noyes Data Corp., Park Ridge, NJ, 1977.


2" PVC PIPE
BACK-FILL
3/4" PLYWOOD
VINYL COVER
GRADE
1/4" PLYWOOD
ASPHALT SLAB
55 GAL. DRUMS

The variation of the Earth Mounded Concrete Bunker concept shown has been tested by the Energy Research and Development Administration. Drums containing transuranic wastes were stacked on top of a below-grade asphalt slab. A plywood housing provided lateral stability to the stacked drums. The bunkers were backfilled with earth after a waterproof cover was placed covering the wastes.

Figure 5. Asphalt Slab Variation of an Earth Mounded Bunker tested by ERDA. Source: modified from W. R. Gilmore, Radioactive Waste Disposal, Low and High Level, p. 274, Noyes Data Corp., Park Ridge, NJ, 1977.

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rectangular bunker type concrete trenches (61 m x 4.9 m x 2.4 m deep) to the currently used cylindrical concrete designs (6 m diam x 4 to 5 m deep) with removable weather-proof caps. Major wastes stored in these facilities include ion exchange resins and filters, Cobalt-60 sources, cell wastes, and irradiated piping.

Ontario Hydro has also used the rectangular concrete structures for storage of LLW. These structures are partly below grade and partly above grade. Whether these structures should properly be termed bunkers or vaults is an open question.

2.3 Operations and Features of an EMCB Disposal Facility

An EMCB disposal facility for LLW would consist of several components or features common to shallow land burial. Some features would be unique requirements for this method. Similarly, some features or components may be considered desirable but not essential under all conditions. These features, if incorporated into the design, could improve the waste isolation capabilities of the disposal units and reduce the need for long-term active maintenance.

The primary unit operations required at an EMCB disposal facility and the major features of such a facility are discussed in this context in the following paragraphs.

2.3.1 Unit Operations

In general the operation of an EMCB disposal facility would be similar in many respects to a trench disposal facility.

Trucks loaded with wastes would be checked in at the entrance, the cargo and manifest checked, and appropriate instructions given to the driver.

The truck would proceed to the secure operations area, i.e., the actual disposal area, or to a temporary storage area, from which the waste packages would be transferred for disposal later.

The waste packages would be unloaded and placed in the disposal units using a mobile crane. After being unloaded, the truck would be surveyed for contamination and decontaminated if necessary before leaving the site.

Other activities would include surveying to establish new disposal area boundaries and disposal unit locations, record keeping for waste receipts, disposal locations, unusual incidents, personnel records including worker exposures, quality control test results, sampling and monitoring data, and permits and licenses.

Sampling and monitoring points must be established and maintained, including surface and subsurface points. Characterization of the subsurface and material properties should continue through the design and construction phase and modifications should be made as necessary to design features to improve performance. Laboratory tests and analyses would be required periodically to verify satisfactory performance and establish a data base from which trends or anomalies could be discerned. Maintenance and repair of equipment and facilities would be required. Personnel training and a certain amount of public relations work would be required.

Clearing and grading of new disposal areas and establishment and maintenance of runoff control features (surface water management) would be required from time to time. Surface grading should direct overland flows away from the disposal units. Drainage should be accomplished by gravity flow for minimum maintenance.

Additional disposal units must be constructed, including necessary appurtenances, such as the French drain, monitored collection and drainage system, etc.

The sequence of events for construction of additional disposal units at the Centre de la Manche in France is discussed below. Certainly, variations of the French practice are possible.

a. A wide trench is first excavated above the water table. Typical dimensions may be 100 m x 30 m x 6 m (Figure 6).

b. The sides of the trench are shaped to have stable side-slopes and the bottom of the trench is covered with a reinforced concrete pad.

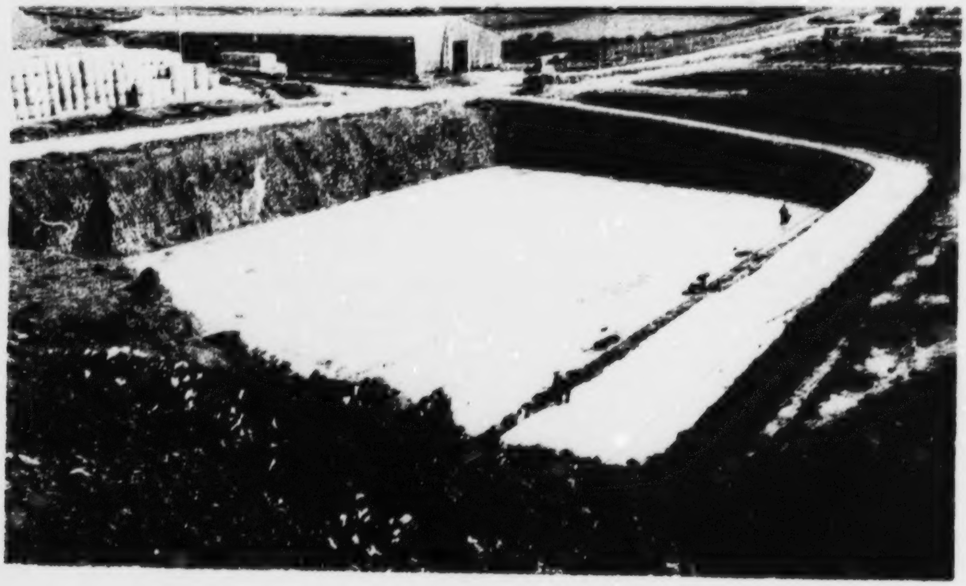
c. A drainage system is provided, on and around the concrete pad to collect any runoff or infiltration which may occur during the construction and initial operation stages, as shown in the exploded view of Figure 2.

d. The trench is subdivided into compartments (approximately 6 m x 6 m x 6 m) with reinforced concrete, cast-in-place panels as shown in Figure 7.

e. Intermediate-level, nonirradiating wastes, which have been packaged and segregated, are lowered by crane into the compartments in successive layers (Figure 8). (The French definition of nonirradiating wastes are wastes that emit less than 200 mrem/hr measured at the surface of the package or 10 mrem/hr measured at a distance of 1 m from the package.)

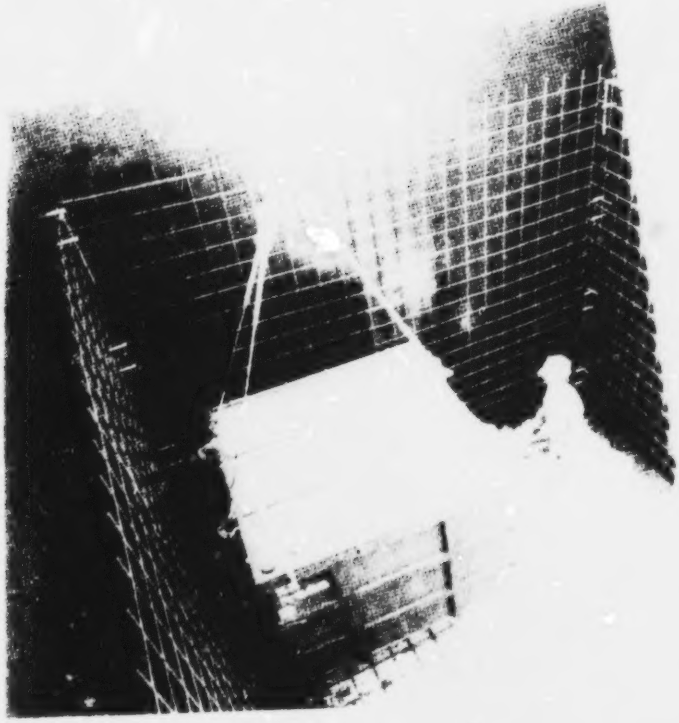
f. After each layer within a compartment is completed, it is backfilled with concrete.

g. When the last layer of waste has been placed in a compartment reinforcing steel is placed on top of the layer, and the compartment is completely backfilled with concrete, embedding the wastes and resulting in one large concrete monolith as shown in Figure 9a.



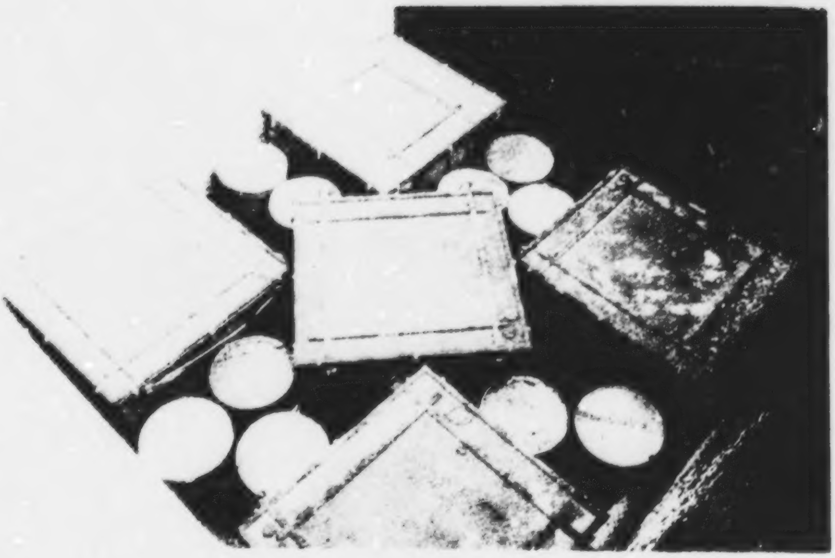
Trench, or pit, excavated for construction of an Earth Mounded Concrete Bunker at the Centre de la Manche in France. The bottom of the trench is covered with a layer of coarse pervious material which in turn is covered with a reinforced concrete pad. A drainage network is provided, on and around the pad to collect runoff or infiltration which may occur during the construction and initial operation stages.

Figure 6. Typical Trench Excavation for Construction of the monolith portion of Earth Mounded Concrete Bunker. Source: Brochure from Commissariat a l'Energie Atomique, "The Centre de la Manche," 1981, available from the Agence Nationale pour la Gestion des Dechets Radioactifs, Paris, France.



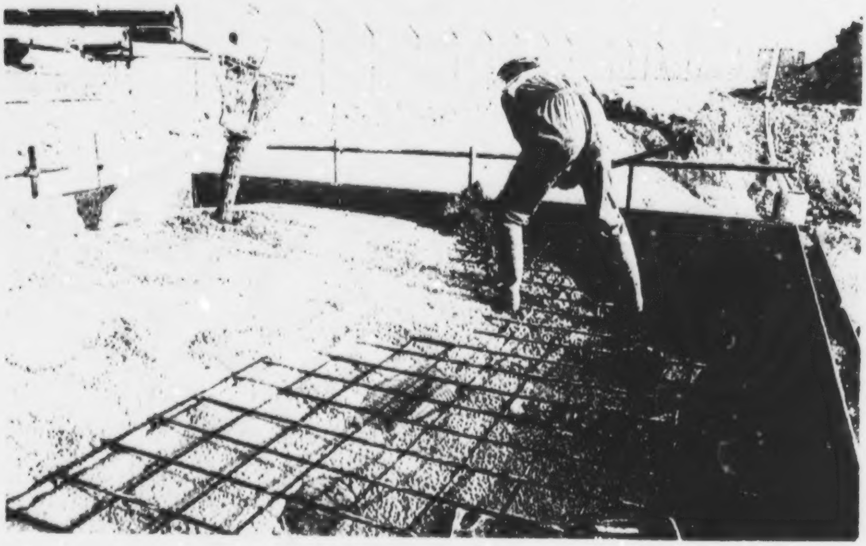
Compartment within an EMCB trench, used for construction of waste-bearing monoliths. The trench is subdivided into compartments, as shown, by panels. Steel reinforcement is placed on the bottom and sides to provide strength to the monolith.

Figure 7. Initial construction of an EMCB monolith. Source: Brochure from Commissariat a L' Energie Atomique, "The Centre de la Manche," 1981, Available from the Agence Nationale pour la Gestion des Dechets Radioactifs, Paris, France.

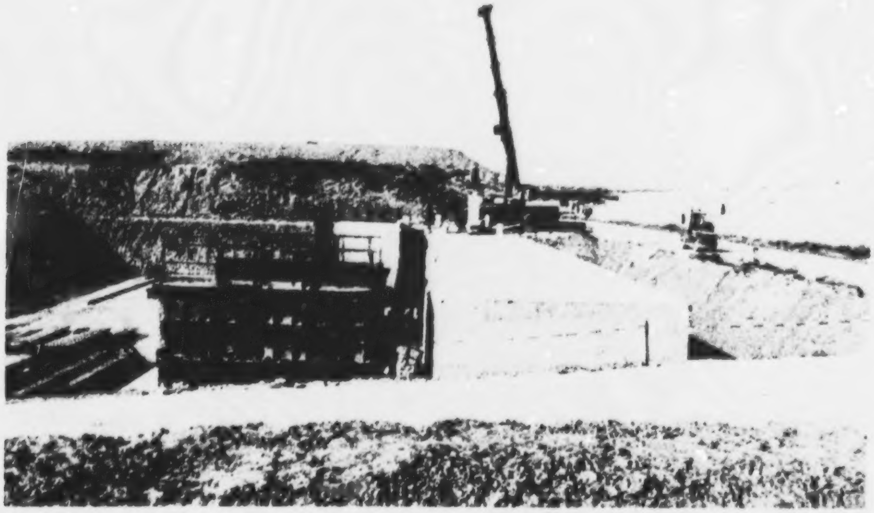


Waste packages are lowered by crane into compartments in successive layers. After each layer is placed, it is backfilled with concrete.

Figure 8. Waste placement in monoliths of an Earth Mounded Concrete Bunker. Source: Brochure from Commissariat a l'Energie Atomique, "The Centre de la Manche," 1981, available from the Agence Nationale pour la Gestion des Dechets Radioactifs, Paris, France.



a. Upon placement of the last layer of waste in a compartment, reinforcing steel is placed on top of the layer, and the compartment is completely backfilled with concrete.



b. Completed monoliths form single, massive reinforced concrete waste bearing units, which are constructed sequentially within the trench.

Figure 9. Final construction of EMCB monoliths. Source: Brochure from Commissariat a l'Energie Atomique, "The Centre de la Manche," 1981, available from the Agence Nationale pour la Gestion des Dechets Radioactifs, Paris, France.

h. The large monoliths are constructed in pairs with a two-meter void between them, which is used for disposal of irradiating wastes (Figure 9b). (The French definition of irradiating wastes are wastes that emit more than 200 mrem/hr measured at the surface of the package or 10 mrem/hr measured at a distance of 1 m from the package.)

i. To reduce the hazard of irradiating wastes, the narrow void between monoliths is temporarily covered by a concrete slab in the interim between placement of wastes.

j. Once the void between monoliths is filled with irradiating wastes, concrete is poured, producing a smaller concrete monolith surrounded by two larger ones.

k. The construction and operation sequence is continued, creating monoliths side by side, until the bunker is filled.

l. Once the last monolith is completed, the large concrete "platform" of monoliths is waterproofed with a layer of asphalt. (The French then backfill the excavation as explained below. The system shown in Figure 2 shows the entire area of monoliths and backfilled excavation covered by a waterproof layer.)

m. Backfill material is placed on the trench slopes to the top level of the monoliths, and another drainage system is installed to catch runoff during further construction, and to monitor infiltration at this level in the facility after closure. Figure 2 shows the backfill as pervious soil. The French use soil from the trench excavation. This material is a clayey weathered schist.

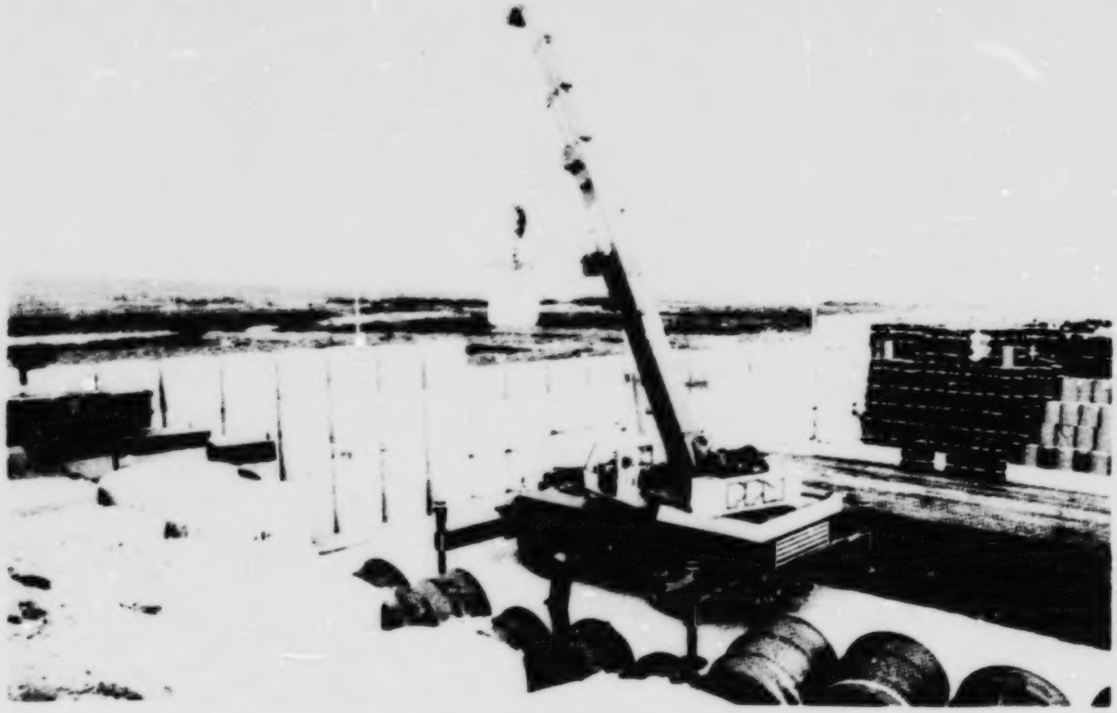
n. Mounds, or tumuli, are constructed on top of the buried monoliths, using the waste packages to form the framework. These packages are typically 2 m^3 concrete blocks with 200 ℓ drums stacked inside the rows of concrete blocks.

o. The concrete blocks forming the structural framework for the mounds are stacked by crane to a maximum height of about 6 m, in rows across the middle, as well as around the perimeter of the monoliths (Figures 10 and 11a and b).

p. Metal drums containing low-level wastes may be placed inside the "compartments" formed by the rows of concrete blocks (Figure 11b).

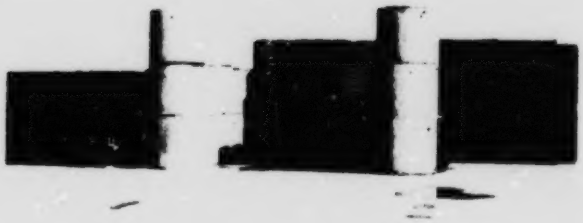
q. Periodically during the placement of the metal drums, cohesionless backfill material is placed to fill the voids between concrete blocks and drums, to reduce the possibility of future settlement, as shown in Figure 12.

r. Along the perimeter the blocks are stacked in a stepped arrangement to give the final tumulus the shape of a sloping mound (Figure 13a).



Construction of the mound or tumulus of an Earth Mounded Concrete Bunker, on top of below grade monoliths at the Centre de la Manche, France. Concrete blocks containing wastes provide the structural framework of the mound and are stacked by crane in rows across the middle, as well as around the perimeter.

Figure 10. Structural framework of an Earth Mounded Concrete Bunker tumulus under construction. Source: Brochure from Commissariat a l'Energie Atomique, "The Centre de la Manche," 1981, available from the Agence Nationale pour la Gestion des Dechets Radioactifs, Paris, France.



a. Compartmentalized storage is provided within the tumulus of an EMCB. At the Centre de la Manche, France, waste bearing reinforced concrete blocks provide the structural framework for the mounds, as well as segmented storage compartments.

b. Metal drums containing low-level wastes which have been placed inside the "compartments" formed by rows of concrete blocks at the Centre de la Manche, France.

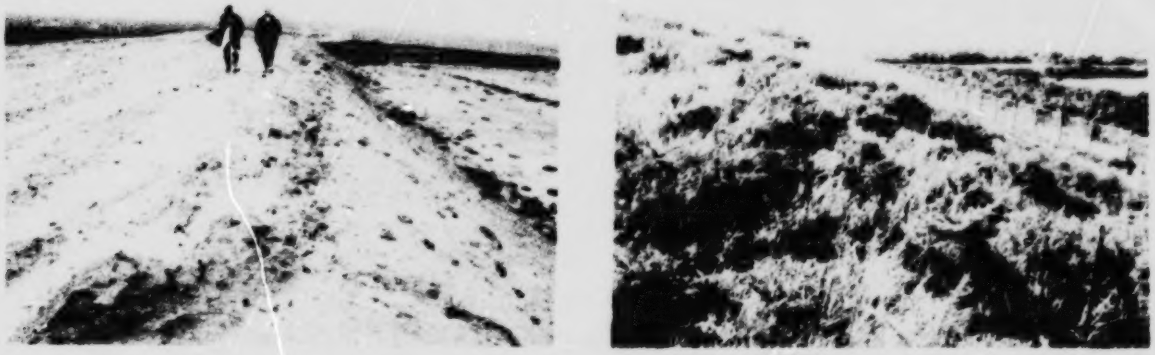
Figure 11. Completed structural framework for an Earth Mounded Concrete Bunker tumulus. Source: Brochure from Commissariat a l'Energie Atomique, "The Centre de la Manche," 1981, available from the Agence Nationale pour la Gestion des Dechets Radioactifs, Paris, France.

Cohesionless backfill material is placed periodically during construction to fill the voids between drums, thus reducing the potential for future settlement, and increasing the stability of the mound.

Figure 12. Backfilling of voids between waste packages within the mound of an Earth Mounded Concrete Bunker. Source: Brochure from Commissariat a l'Energie Atomique, "The Centre de la Manche," 1981, available from the Agence Nationale pour la Gestion des Dechets Radioactifs, Paris, France.

a. Shape of the tumulus is initially formed by stacking the blocks around the perimeter in a stepped arrangement.

b. The tumulus is built-up using a low permeability material to minimize infiltration.



c. Final shape of the tumulus is attained after the blocks and compartmentalized wastes have been completely covered.

d. A completed Earth Mounded Concrete Bunker at the Centre de la Manche, France.

Figure 13. Construction sequence of a tumulus of an Earth Mounded Concrete Bunker. Source: Brochure from Commissariat a l'Energie Atomique, "The Centre de la Manche," 1981, available from the Agence Nationale pour la Gestion des Dechets Radioactifs, Paris, France.

s. When all concrete blocks and metal drums have been emplaced, the backfill material is placed over the entire stock, to fill all voids between the packages, and to increase the stability of the completed earthen mound.

t. The entire mound is then covered with a thick layer of impermeable clay, which in turn is covered with a layer of topsoil (Figure 13b and c).

u. The facility, which now forms a tumulus or earthen mound, is then surrounded by a final drainage system designed to collect rainwater flowing over the clay layer (see Figure 2).

v. The EMCB is completed by planting the newly formed tumulus with native vegetation to stabilize the surface soil and encourage drying (Figure 13d).

The monitoring program for EMCB's includes analysis of water collected in the drainage network, monitoring and periodic checks on the ground water, a meteorological station for monitoring and collecting rainfall for analysis, measurements of radioactivity in the air, dosimeters at strategic locations to monitor radiation levels, and a strict monthly reporting procedure. Additional technical requirements for EMCB's include that the locations of waste packages and their contents, in both the tumuli and the monoliths, be recorded on a disposal plan and stored on microfilm in several different places.

2.3.2 Features and Components

The primary features and components of an EMCB disposal facility are described below:

a. The actual disposal site including the land for disposal areas, disposal units, buffer zones, and auxiliary operations. These components are discussed separately below. Specific unit configuration, such as size, orientation, and spacing are not specified, but considerations for architectural or construction components such as the excavation, floor, walls, monoliths, and covers are presented.

b. Excavation. The size excavation required for initial construction of an EMCB is dependent upon the physical size and topography of the disposal site, and the projected volume of waste to be disposed. The depth of excavation must be site-specific, and depends primarily upon the depth to the ground-water table, depth to bedrock, and the stability of the sidewalls. A typical trench excavation is shown in Figure 6 and in the exploded view of an EMCB in Figure 2.

Characterization of the subsurface, and material properties, should continue through the design and construction phases, and design modifications should be implemented on an as needed basis to assure sidewall stability. Reinforcing or lining materials may be used to stabilize the excavation sidewalls at sites with marginally stable soils, which may otherwise require unusually low slope angles. Erosion of the sidewalls should be prevented to assure that the efficiency of drainage system is not threatened by in-filling.

c. Excavation Floor. The bottom of the excavation should be covered with a low permeability barrier, such as concrete, to contain or collect any runoff or infiltration which may occur during the construction, operations, or closure phases. The trench floor should be durable enough to withstand construction operations, should be chemically stable in the subsurface environment, and should be sufficiently flexible to accommodate minor foundation differential settlement without rupture.

The floor slab and foundation of the trench are required to support not only construction activities, but the weight of relatively massive belowground monoliths and the aboveground tumulus. To meet the foundation support requirements, reinforced Portland cement concrete is generally recommended for an EMCB trench floor. A comprehensive discussion of the considerations required to assure stability of concrete materials is presented in Appendix A (Denson, 1985) and the information and recommendations are directly applicable to EMCB's.

d. Subsurface Drains. A drainage system must be provided, both on and around the constructed excavation floor to collect any runoff or infiltration which may occur during the construction and operation phases. The trench floor may be sloped to the sides or small drainage channels may be constructed on the top surface of the floor to facilitate drainage from the disposal unit floor during operations, as well as after completion of the belowground monoliths. A French drain should also be constructed completely encircling the disposal unit floor. Both the slab drains and the French drain, shown in Figure 2, should be sloped along the length of the trench to a sump, or sumps. The sumps provide monitoring points, as well as, intake points for pumping any collected seepage water.

e. Monoliths. Belowground monoliths constructed within the trench provide not only LLW storage and isolation, but form the base for the aboveground tumulus. Strength and stability are, therefore, required for the service life of the disposal facility. The strength and stability requirements can be met using standard practice. Normal deterioration of concrete with age may result in lower strengths but the structure should retain sufficient strength and stability to perform satisfactorily.

Materials and construction practices described for the trench floor are, therefore, applicable and should be followed in construction of the monoliths. The vertical sidewalls required for forming the monoliths shown in Figure 6, should be constructed of reinforced concrete with care given to prevent aggregate settlement and/or inclusion of air voids during placement. The "Building Code

Requirements for Reinforced Concrete" (ACI, 1963) provide the minimum recommended design and construction procedures for monolith wall construction.

f. Backfill. Backfilling operations required for filling each monolith with concrete were presented in section 2.3.1 of this report. Upon completion of all monoliths within a given trench, a pervious backfill should be placed and compacted around the monoliths. This recommendation differs from the French practice of using materials from the excavation as backfill. A graded filter material should be placed between the monolith base drainage system and the backfill material. Any water entering the backfill will flow into the trench floor drainage system and French drain.

g. Surface Sealing Cap. Prior to construction of an aboveground mound, or tumulus, the top of the buried monoliths, as well as the compacted backfill should be sealed. A low permeability layer should be placed entirely over the belowground monoliths and compacted backfill, and extend laterally sufficiently to prevent water movement from the edges to the trench excavation. This recommended practice should enhance performance over the French practice of sealing only the surface above the concrete monolith. Atop the low permeability layer, a working surface must be prepared for constructing the tumulus. As with the trench floor, the aboveground working surface must be sufficiently durable to prevent cracking or rupture and be chemically stable.

h. Surface Drains. The surface of the aboveground working-pad may be sloped to promote drainage away from the storage area, or as with the trench floor, a drainage system may be provided on and around the constructed working surface, to collect runoff during construction and operations, and infiltration or percolation after completion. This drainage system may be connected (via galleries or drop inlets) to the monolith-base drains and sump(s) as done at the Centre de la Manche. If so, separate catchment areas should be provided for independent radiological monitoring of the upper and lower drainage systems. Alternatively, the drainage systems may be kept separate for better identification of the location of any leaks or radionuclide migration problems.

i. Mound Framework. A structural framework should be provided to enhance the stability of the aboveground mound. Such a framework should be compartmentalized, for segmented disposal, as shown in Figure 11, and provide sloping sides to facilitate final construction of a gently sloping mound, Figure 13.

The structural framework for a mound may be provided by reinforced concrete wingwalls, or built-up using large reinforced concrete blocks, as done at the Centre de la Manche and shown in Figures 10 and 11a and b. The use of concrete blocks offers an attractive alternative construction option because LLW may be encapsulated within the blocks.

Placement of wastes and subsequent backfilling around the wastes in the mound "compartments" were presented in section 2.3.1. A mound is created by sequential placement of wastes and coarse backfill until the final height and shape are obtained.

j. Mound Cover. A low permeability layer of clay, several feet in thickness, should be placed over completed EMCB mounds to minimize infiltration into the unit. The clay should be covered with a layer of sand and gravel to promote drainage from the mound. The layer should extend to the surface drainage system surrounding the mound at the original or modified grade. As a final cover over each EMCB a layer of topsoil should be placed and seeded to resist erosion.

k. Runoff Control Features. In humid climates, the completed EMCB should be encircled with a final surface drainage system which is designed to collect surface runoff, as well as percolating water flowing over the surface of the impervious clay layer. Drainage channels should flow by gravity to a central collection, monitoring, and control point prior to discharge.

In arid areas it may be possible, with appropriate documentation and assurance, to reduce the requirements for surface drainage systems. In such areas, however, the establishment of a vegetative cover is much less certain, and a layer of gravel or rock armoring over the mound may obtain the same result.

l. Overpack container fabrication and storage areas. This facility may or may not be necessary or desirable, depending on the plan of operations and customer needs.

m. Testing laboratory, including necessary testing equipment and computer facilities for storage, retrieval, plotting and analysis of test and monitoring data. It is considered important to have these facilities onsite to avoid delays between sampling and testing. In this way, the site manager and his staff can quickly detect any abnormalities or trends that might develop and take action as needed to correct them. Quality control testing equipment should include apparatus to sample and test site cast concrete, backfill moisture and density, and waste package integrity.

n. Monitoring devices, including weather stations, air sampling stations, water sampling devices, wells, and piezometers. In the authors' opinion, a monitoring well should be installed at each overall disposal unit. Monitoring wells should be installed with the screened portion reaching the bottom of the drainage layer so that any water that collected could be pumped out. This water should be measured, sampled, and analyzed. Piezometers that extend below the zone of fluctuation of the water table should be installed downgradient from each disposal unit to allow periodic checks of water levels and samples to be taken.

o. A truck wash and decontamination facility is recommended. The waste water must be properly treated and disposed of.

p. Personnel and clothing decontamination facilities should be available.

q. An equipment storage building should be provided.

r. A temporary waste storage area should be available, including unloading facilities, for use in case of temporary shutdown of disposal operations due to inclement weather or during periods of peak waste receipts. This storage area should be designed to minimize contact of rainfall and runoff water with waste packages.

s. Operating equipment, including some or all of the following:

(1) Pickups and vans for transporting personnel and visitors.

(2) Trucks and trailers for transporting waste packages, construction materials, and heavy equipment.

(3) Elevating scrapers for excavation of disposal units and placement of fill for covers.

(4) Front end loader/backhoe excavator to excavate French drains, remove spoil and place backfill and drainage material.

(5) Forklift for use in temporary storage operations.

(6) Drill rigs for exploration boreholes, piezometers and wells.

(7) Mobile crane for placing waste packages.

Note: The sizes, number required, and even the need for some of the above equipment would be dependent on the operating plan, site conditions, and customer needs. Some of the needs might be met through short term contracts for either equipment or services or both.

t. Nominal inventory of spare parts and tools for repairs to vital or emergency equipment.

u. Security fences, guard shacks, and truck check in station for control of access and egress.

v. Operations building from which all disposal operations would be initiated.

w. Administration building which should include facilities for office work, records storage and retrieval, including personnel records, visitor waiting room facilities, convenience facilities, and storage areas. Ample parking areas should be provided. The administration building should be outside the secure operations area to minimize the number of employees and visitors that must be checked in and out.

x. Access roads for transportation of wastes from entrance to disposal units and for maintenance and monitoring.

To assure that roads on the site do not interfere with EMCB closure or stabilization, they must be located so that construction equipment and other vehicles do not damage completed or partially closed units during normal operational activities. In addition, road surfaces should be designed to avoid providing areas of either concentrated infiltration or runoff which could possibly interfere with design objectives, e.g., minimizing infiltration, providing of a stable site surface, or establishing a vegetative cover (Pangburn and Pennifill, 1982).

y. A repair shop including tools and facilities for maintenance and repair of operating equipment and fabrication, modification, or repair of special devices, equipment, or sampling and testing equipment.

z. Survey markers and survey equipment.

2.4 Performance Capabilities

Experience gained in France since 1969 with EMCB's has shown the concept to be an effective and attractive disposal method. The performance objectives of protection of the general population, protection of individuals from inadvertent intrusion, and protection of individuals during operation appear to have been satisfactorily met and public acceptance has been satisfactory. An extensive monitoring network in and around completed earth mounded concrete bunkers at France's disposal site, the Centre de la Manche, has detected no significant radionuclide migration. A governmental organization, the Agence Nationale pour la Gestion des Dechets Radioactifs (ANDRA), was established in 1979 to maintain access control of the repository for a period of up to 300 years after closure of the site, to prevent inadvertent intrusion, and to assure that the site remains stable after closure.

The advantages of this alternative result from positive control and containment of the wastes. The encapsulation and multiple barrier approach allows some flexibility in siting the facilities and minimizes the possibility of inadvertent intrusion. Stability of the wastes within EMCB's may be confirmed from examination of sample test data available from extensive drainage and monitoring networks. Such networks are easily incorporated into the design of EMCB's.

Structural considerations for EMCB's include the design and construction of stable trenches and slopes, waterproof barriers, drainage and monitoring networks, and concrete slabs and panels.

The disadvantages of EMCB's are primarily economic. Because of the design and construction, EMCB's are obviously more expensive than conventional trench disposal.

3. TECHNICAL REQUIREMENTS FOR EMCB DISPOSAL OF LLW

In this section, the technical requirements thought to be necessary for evaluation of site suitability, design, operations, closure, and monitoring are developed.

The pattern of development used for each section is:

a. First, each existing criterion for near-surface disposal is quoted, including the subparagraph number of 10 CFR 61 Subpart D under which it appears.

b. The criterion is discussed and judged as to its relevance to EMCB disposal.

c. A recommendation is made to:

   (1) Retain the criterion as is.
   (2) Not apply the criterion to the evaluation of this alternative.
   (3) Modify the criterion to make it applicable for evaluation of this alternative.

Any recommended modifications to the existing criterion are underlined. Words that are recommended to be deleted are indicated by a dash through each letter. Any departures or changes in recommendations from the position taken in the Task 1 report (Bennett and others, 1984) are noted.

At the end of each section (site suitability, design, operations and closure, and monitoring) technical requirements implied from 10 CFR 61.12 relative to these topics which are not covered by existing criteria are discussed. Specific criteria in prescriptive language are not given. Rather the points that should be addressed and the reasoning behind them are stated. This method of presentation is thought to be more appropriate than offering specific criteria, as it allows the Commission to consider those issues and develop specific wording that it considers appropriate on a point by point basis.

3.1 Site Suitability

3.1.1 Role of Site Characteristics

The primary emphasis in disposal site suitability is given to the long-term attainment of the performance objectives of 10 CFR Part 61, Subpart C.

Site characteristics should not only facilitate design and construction, but also promote the ease of the operations and closure phases. The primary role of site characteristics, however, will be to promote the stability and isolation of wastes in the event of failure of any system component.

Sole reliance on site characteristics for meeting the performance objectives is not a requirement, recognizing that collective use will be made of site characteristics, design features, operations and closure methods, waste-form management, and institutional controls. Since disposal facilities may be constructed in many different geographical areas, it is anticipated that the sites will reflect a wide range of geologic, hydrologic, meteorologic, climatic, environmental, and socioeconomic conditions. The contribution of site characteristics toward stability and isolation of wastes, therefore, may vary from site to site.

In general, the reliance which can be placed on design features and maintenance tends to decrease with increasing time after closure. Therefore, tradeoffs related to the degree of reliance placed in site characteristics, design features, or methods of facility operation and site closure should be made with the goal of maximizing the long-term contribution toward public health and safety (Siefken and others, 1982).

Site characterization may be defined as a program of investigations and tests, both in the field and laboratory, undertaken to define the site characteristics affecting the isolation of the LLW and long-term stability of disposal sites. Characteristics of the disposal site and surrounding vicinity which must be determined should include, but not necessarily be limited to, the geological, geomechanical, hydrological, meteorological, and climatological characteristics.

3.1.1.1 Geological and Geomechanical Characteristics

A regional geological framework, including the stratigraphy, tectonics, structure, and physiography, must be established for a proposed site. Detailed geologic information, required for site modeling, should be obtained by surface mapping, exploratory boreholes, surficial geophysical surveys, borehole geophysical logging, and test pit excavations.

Geomechanical characteristics of the site soil and rock deposits are required for evaluation, as well as design and analyses. Performance parameters such as the coefficient of consolidation, permeability, cohesion, angle of internal friction, unconfined compressive strength, and deformation modulus should be determined, as appropriate, for the soil and rock types. Index properties, such as water contents, unit weights, Atterberg limits, SPT blow count, cone penetration resistance, particle-size distribution, void ratio, organic content, and RQD should be determined for classification, as well as design purposes. Bearing capacity and settlement should be predicted from appropriate soil properties and structural loads and layout.

3.1.1.2 Hydrological Characteristics

Surface water and ground water represent the most significant pathways for potential long-term releases to the general population. Proper characterization of the hydrological conditions requires both site-specific and regional data. Surface water studies should include aerial photography and topographic mapping, as well as the determination of drainage areas, flood flow frequencies, runoff rates, infiltration rates, flow rates, and flow volumes.

To define the hydrological and stratigraphic framework, site characterization studies should be performed to identify and characterize the separate hydrogeologic units underlying the site, including their lithology, thickness, lateral extent, continuity, inclination, areas and modes of recharge and discharge, piezometric levels, hydrochemistry, interrelationship with adjacent hydrogeologic units, and interrelationship with surface water bodies.

The hydrological characteristics of the site should be used to develop flow and transport models with which migration of potential releases may be evaluated. In addition to modeling the surface and subsurface hydrology, ground truth documentation should be obtained by laboratory and field tests. Data collection or sampling points should be established which will not only verify model predictions, but which may continue to be used throughout the design and construction phases and, eventually, for long-term monitoring.

3.1.1.3 Meteorological and Climatological Characteristics

Site meteorological and climatological data are required to determine a water budget, establish the ranges and frequency of occurrence of unusual phenomena, and perform atmospheric dispersion analyses. The NRC staff (Siefken and others, 1982) recommends that an onsite meteorological station should be established and operated a minimum of one year during site characterization to obtain site-specific data. Existing long-term data should be obtained from the National Oceanographic and Atmospheric Administration. The onsite meteorological station should be incorporated into the eventual site monitoring program to verify data used for the evaluation and characterization.

3.1.2 Assessment of Existing Criteria

The existing criteria for assessment of near-surface disposal site suitability are contained in 10 CFR 61 Subpart D, paragraph 61.50.

Criterion 61.50 (a)(1) states: "The purpose of this section is to specify the minimum characteristics a disposal site must have to be acceptable for use as a near-surface disposal facility. The primary emphasis in disposal site suitability is given to isolation of wastes, a matter having long-term impacts, and to disposal site features that ensure that the long-term performance objectives of Subpart C of this part are met, as opposed to short-term convenience or benefits.

Discussion. Disposal of LLW in earth mounded concrete bunkers is similar in many respects to near-surface disposal in trenches. Consequently, most of the features that would make a site suitable for trench disposal would also make a site suitable or desirable for EMCB disposal facility.

Recommendation. This criterion states the goal of all subsequent site suitability criterion. Therefore, the criterion should be retained as is.

Criterion 10 CFR 61.50 (a)(2) states: "The disposal site shall be capable of being characterized, modeled, analyzed, and monitored."

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Discussion. This criterion is necessary to ensure that the long-term performance objectives are met. Many sophisticated analytical tools have been developed to model natural systems, e.g., 2-D and 3-D computer simulations for analysis of ground-water movement, and sophisticated analyses of slope stability.

However, all models and analyses depend on sound judgment and reliable input data (strengths, permeability, depth to water table, etc.) to reach correct solutions.

The NRC staff (Siefken and others, 1982) points out that models tend to homogenize stratigraphic units and average the hydrologic properties to satisfy assumptions and boundary conditions. Therefore, the site characteristics used as model inputs must vary over a sufficiently narrow range so that the simplified inputs and assumptions are valid. Sedlett and others (1982), Cherry, Grisak, and Jackson (1974), and Cherry and Gilham (1977) have discussed this issue and indicated that monitoring to measure the necessary site characteristics is much more complex and less reliable for geologically complex sites. Sedlett indicated that it may be impossible to get adequate, reliable data from sites underlain by fractured rock. Even sophisticated, expensive site investigations only sample a small fraction of the subsurface, so extrapolation over wide areas at highly variable sites is unreliable.

Simply put, the more uniform the site and the natural processes occurring on it, the less complex and costly the site investigation may be, and the more reliable predictions will be.

Recommendation. This criterion should be retained as is.

Criterion 61.50 (a)(3) states: "Within the region or state where the facility is to be located, a disposal site should be selected so that projected population growth and future developments are not likely to affect the ability of the disposal facility to meet the performance objectives of Subpart C of this part.

Discussion. The objectives of this criterion are to minimize the risks of exposure of the general population to releases of radioactivity and to minimize the risks of inadvertent intrusion. The objectives can be met using census data and urban planning studies to develop site-specific population and development projections. However, data and projections from existing planning studies may decrease in reliability as the time period of interest increases.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.50 (a)(4) states: "Areas must be avoided having known natural resources which, if exploited, would result in failure to meet the performance objectives of Subpart C of this part."

Discussion. The goal of this criterion is to avoid the possibility of compromising site integrity caused by future exploration or exploitation of the natural resources adjacent to or underlying the disposal site. Examples may include deep borings for oil exploration or exploitation of ore by mining. A less obvious example might be a deep water well. Such wells, if pumped at rates much higher than the ground-water recharge rates, can cause surface subsidence and cracking of the surface. This phenomenon is a serious problem in the arid southwestern U. S. and is discussed later in the section on additional technical considerations. The goal of the criterion is sound. Further, practical application of the criterion is not likely to preclude or significantly limit the selection of suitable sites within a given region or state.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.50 (a)(5) states: "The disposal site must be generally well drained and free of areas of flooding or frequent ponding. Waste disposal shall not take place in a 100-year floodplain, coastal high-hazard area or wetland, as defined in Executive Order 11988, "Floodplain Management Guidelines.""

Discussion. The desirability of a well-drained site free of areas of flooding or frequent ponding can be readily understood. Open, flooded excavations would have to be pumped dry. Trench sidewalls might erode or fail by sliding. Equipment could be damaged or immobilized, making it impossible to take damage prevention or remedial measures.

The second part of the criterion, which prescribes avoidance of legally defined flood prone areas is technically achievable using existing maps, rainfall and runoff data, and appropriate hydrological models.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.50 (a)(6) states: "Upstream drainage areas must be minimized to decrease the amount of runoff which could erode or inundate waste disposal units."

Discussion. The above criterion has as its primary goal, the prevention or minimization of damage from flash flood situations. This situation is more likely in areas of higher topographic relief.

The criterion, therefore, implies that the disposal units should be located on high ground, i.e., the ridgetops and plateaus, but protected valleys or relatively flat lands are not excluded. This requirement is technically sound.

Recommendation. The criterion should be retained as is. This recommendation is a departure from the Task 1 report recommendation, where the inundation of completed EMCB's was pointed out as being unlikely. However, the avoidance of inundation is important and the objective of the criterion is valid and achievable.

Criterion 10 CFR 61.50 (a)(7) states: "The dispoal site must provide sufficient depth to the water table that ground-water intrusion, perennial or otherwise, into the waste will not occur. The Commission will consider an exception to this requirement to allow disposal below the water table if it can be conclusively shown that disposal site characteristics will result in molecular diffusion being the predominant means of radionuclide movement and the rate of movement will result in the performance objectives of Subpart C of this part being met. In no case will waste disposal be permitted in the zone of fluctuation of the water table."

Discussion. The goal of this requirement is to avoid contact of waste packages and ground water. Ground water is considered to be the major pathway of release in humid areas. Contact of water and waste packages also hastens the rate of package deterioration and radionuclide migration. The criterion does not specify the depth between the water table and the disposal unit. This depth must be determined from measurement and analysis of site characteristics. These characteristics include the coefficient of permeability, the degree of homogeneity of the site soil and rock deposits, whether preferential flow paths exist, and the degree of fluctuation of the water table. The impacts of present and projected land uses on the regional water table should not be overlooked.

The criterion provides a possible exception for construction of a disposal unit below the water table, specifically avoiding the zone of fluctuation. Since EMCB's are constructed both above and below ground level, any potential contact with the water table would place at least part of the facility in the zone of fluctuation. Therefore, in no case could the EMCB disposal alternative be used below the water table. While the criterion is judged to be applicable, the exception is not.

Recommendation. The criterion should be retained as is with the understanding that the below water table disposal option does not apply to this alternative. This recommendation is consistent with the intent of the Task 1 report recommendation to point out the inapplicability of this portion of the criterion. However, no modification to the criterion is required.

Criterion 10 CFR 61.50 (a)(8) states: "The hydrogeologic unit used for disposal shall not discharge ground water to the surface within the disposal site."

Discussion. Location of a disposal unit in a formation that discharged ground water to the surface within or even near the site should be considered unsafe and unnecessary. It is relatively simple to uncover evidence of springs early in the site investigation. Such occurrences should be grounds for exclusion of that particular site from further consideration.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.50 (a)(9) states: "Areas must be avoided where tectonic processes such as faulting, folding, seismic activity, or vulcanism may occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of Subpart C of this part, or may preclude defensible modeling and prediction of long-term impacts."

Discussion. The performance objectives to which this criterion refer are equally applicable to any LLW disposal alternative. However, the degree to which seismic activity might impair disposal site performance would vary significantly for different disposal concepts, or even for the same alternative, if built to withstand different design basis natural events.

Appropriate design features of an EMCB may allow favorable determination of suitability of a site for areas demonstrating various degrees of seismic intensity. For those cases where resistance to tectonic forces is included in the design, the site characterization must include determination of the maximum probable seismic event in terms of accelerations, particle velocities, and wavelengths of the vibrations.

Since the disposal site is defined in 10 CFR 61.2 to consist of the disposal units and buffer zone, the objective of the criterion could be met using appropriate seismic design and construction methods. Consequently, the criterion is directly applicable.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.50 (a)(10) states: "Areas must be avoided where surface geologic processes such as mass wasting, erosion, slumping, landsliding, or weathering occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of Subpart C of this part, or may preclude defensible modeling and prediction of long-term impacts."

Discussion. The goal of this criterion is valid. Serious erosion could uncover the waste packages if left uncorrected. Slumping soils and landslides could damage drainage layers or monitoring wells. Weathering of site geologic materials can result in swelling, increased erosion, and significant changes in infiltration rates. Areas undergoing rapid geological processes can usually be identified during the screening process through analysis of aerial photographs taken a few years to tens of years apart. Such areas can be eliminated at this stage without seriously limiting the availability of suitable sites within a state or region.

Recommendation. The criterion should be retained as is. This recommendation differs from the position stated in the Task 1 report. The recommended modifications to address subsurface geological processes stated in the Task 1 report are discussed under the "Suggested Additional Technical Considerations" section of this report. These issues are not properly described as surface geological processes.

Criterion 10 CFR 61.50 (a)(11) states: "The disposal site must not be located where nearby facilities or activities could adversely impact the ability of the site to meet the performance objectives of Subpart C of this part or significantly mask the environmental monitoring program."

Discussion. This requirement is generally applicable to any LLW disposal facility. It does not preclude selection of a disposal site near other facilities. It does require an assessment of the potential adverse impacts of such a decision. This assessment can only be made on a site specific basis.

Recommendation. The criterion should be retained as is.

3.1.3 Suggested Additional Technical Considerations

Additional technical considerations for demonstrating site suitability should include requirements to determine the existence and potential adverse impacts of dispersive soils, liquefiable soils, corrosive soils, expansive soils, karstic or cavernous areas and areas of land subsidence at a potential disposal site.

The potential problems caused by occurrence of such deposits are discussed below.

3.1.3.1 Dispersive Soils

The occurrence of dispersive soil deposits in or near the geohydrologic unit used for disposal can result in accelerated erosion, piping, and collapse of the surface.

Pinhole erosion tests can provide evidence of the susceptibility of soils to dispersion (Sherard and others, 1977). High percentage (greater than 60 percent) of sodium in total dissolved salts is also an indicator of dispersive clays. Dispersive soils cannot be identified by conventional index tests such as Atterberg limits or particle size distribution (Perry, 1979). Visual inspection of cut slopes and embankments can uncover dispersive soils problems. Visual inspection is not very helpful for undisturbed sites because dispersive clays are usually not present in topsoil due to the process of eluviation (movement of clay particles downward in the soil profile). Therefore natural deposits may show little or no evidence from surface appearance that the underlying soil may be dispersive. The piping channels that develop in the underlying soil can be obscured by the vegetative cover and bridging of the topsoil deposit. Eventually, this top layer will collapse into the hole as erosion damage progresses.

In excavated slopes and man-made embankments the dispersive characteristics are more readily observable. Excavated slopes in dispersive clays exhibit rill erosion, surface cracking, and vertical erosion tunnels resembling badlands topography (Perry, 1979).

Embankments constructed of dispersive clays, even with good vegetative cover, also develop rainfall erosion tunnels called cave-ins or jugs. In the author's opinion, the primary risk to disposal units constructed in dispersive soil is from piping erosion. If the backfill placed around the waste packages is not properly compacted, interconnected cracks and voids could provide preferential paths for infiltrating water. These paths could become much larger with time as water erodes the cracks further. Eventually, the cover could collapse, requiring repair.

If the infiltrating water exits through a shrinkage crack or pipe along the side slope of a ridge, the erosion could lead to local instability of the slope and ultimately to failure.

Measures are available to avoid problems if the dispersive nature of the soil is recognized before construction. For example, sand filters can be used to seal and safely control leaks in dispersive clays.

Lime treatment has also proved effective in reducing tunnel erosion in dispersive clay dams (Forsythe, 1977; Phillips, 1977; and Rosewell, 1977). The calcium in lime is believed to result in a significant reduction in shrinkage and a lower percentage of exchangeable sodium (and a higher percentage of exchangeable calcium) actually going into solution, thereby reducing the dispersive erosion.

3.1.3.2 Corrosive Soils

The occurrence of corrosive soils in humid areas could result in deterioration of disposal unit barriers, e.g., concrete backfill, drains, and waste packages. The potential risk from corrosive soils is much smaller in arid regions. Chemical analyses can be used to determine whether a potential problem exists. If so, design and construction measures can be implemented to reduce the impact such as the use of sulfate resistant concrete. In the authors' opinion, otherwise suitable sites should not be disqualified on the basis of occurrence of corrosive soils alone.

3.1.3.3 Solution Cavities

Solution cavities are formed in carbonate and sulfate rocks such as limestone, dolomite, marble, and gypsum by the action of slowly moving ground water that dissolves the rock to form tunnels and caves. Most of the caves in the world, including the largest, are of this type. Disposal in hydrogeologic units above carbonate formations that are actively being dissolved should be avoided. Solution cavities can result in collapse of overlying strata used for disposal or which serve as aquicludes.

The occurrence of solution cavities can also result in significant unpredictable alteration of ground-water seepage patterns and quantities which would preclude reliable modelling.

Because of their discrete locations, the probability of locating solution cavities through normal site investigations is low. Geophysical methods have been successful in some cases. With borings, it is literally a hit or miss situation. Obviously, the probability of missing an existing cavity is higher than that of hitting it.

Even if they are reliably located, solution caverns must be grouted to fill the voids. It is costly and difficult to fill completely all voids and impossible to ensure that solutioning will not continue adjacent to the grouted interface.

Regional geological data can provide general evidence to indicate the occurrence, depth, and lateral extent of known karstic formations. These areas should in general be avoided.

3.1.3.4 Liquefiable Soils

Liquefaction of sand deposits has caused extensive damage in numerous seismically active areas of the world, e.g., Japan, Alaska, and California. Less publicized cases of liquefaction of sensitive clays have also caused extensive damage in Norway where marine deposits have liquefied after only minor disturbances. These occurrences were preceded by leaching of salts in the clay by ground water moving downward from mountainous areas to the sea. These clays lose strength as the salts are removed, and in many locations near the sea, a state of near equilibrium exists. Even minor disturbances, such as excavating a building foundation or farm pond, have been known to initiate liquefaction of these deposits. Once started, wide areas can be progressively affected.

More common incidences of liquefaction can be observed along many streams and rivers after prolonged high water conditions. The water level in the stream drops faster than the water table in the stream banks, leading to instability and failure. Not all such incidences can be properly called liquefaction but many are.

The potential risk to LLW disposal facilities from liquefaction is small because most sites with liquefiable deposits have other characteristics that make them undesirable. For example, the site may be near a coastal high hazard area or soil permeability may be too high.

The main danger would be the failure to recognize the liquefaction potential of deposits above or below the hydrogeological unit used for disposal.

3.1.3.5 Expansive Soils

Volume change of expansive soil subgrades resulting from moisture variations frequently cause severe pavement damage. Highways constructed in the Southwest, Western Mountain, Central Plains, and Southeast geographical areas are particularly susceptible to this type of damage.

A 1972 survey (Lamb and Hanna, 1973) of all the 50 states, Puerto Rico, and the District of Columbia indicated that 36 states have expansive soils. Expansive soils are so areally extensive within parts of the US that alteration of highway routes to avoid the material is virtually impossible.

The annual cost of damage to streets and highways caused by expansive soils was estimated in 1973 to exceed $1.14 billion (Jones and Holtz, 1973).

Additional damage to slab on grade buildings was not estimated but was and is substantial.

Although this damage is of much concern to state and Federal highway officials and local building officials, expansive clay problems do not occur in every state. Likewise, problems do not occur uniformly over areas in which expansive soils are found. The key geological factors in determining a geologic units' expansive nature or "swell potential" are clay mineralogy and amount of clay or shale within a geologic unit. Clay mineralogy, specifically montmorillonite content, can be used to estimate the degree of expansiveness, whereas the frequency of occurrence can be related to the amount of clay or shale in the geologic unit (Snethen, 1979).

One other essential factor that determines whether expansion actually occurs is the availability of water. Without water the soil will not swell. Likewise, if water is available year round, the soil will swell to its full potential under existing loading conditions and no further volume change will occur.

Consequently, the problems caused by expansive soils occur primarily near the surface within the zone of seasonal soil moisture changes. Damage usually takes the form of buckled, warped, and heaved slabs, cracked masonry walls, and general distortion of the structure. For the case of engineered disposal facilities, damage is likely to occur if concrete slabs or walls are cast in direct contact with expansive clays. The potential for damage is exacerbated if the slab is cast over an excavation, because the soil has been unloaded by the excavation and the moisture equilibrium has been disturbed.

Methods are available to minimize or prevent damage from expansive soils. For example, form voids made of heavy corrugated paper are sometimes used beneath slabs to allow space for the soil to swell without damage. The slab must be supported on reinforced grade beams, founded on piers that extend below the zone of seasonal moisture change. The grade beams must not be in direct contact with the surface soil. End-bearing piers founded within the zone of moisture change may heave upward because of the high swelling pressures. The opposite problem of piers settling significantly because of negative skin friction as the clay desiccates during dry periods can also occur. This problem can be dealt with by providing a low-friction membrane between the pier and soil to reduce skin friction.

However, all the engineering fixes have 2 things in common. They rely on discovery of the expansive nature of the soil before construction and they add to the construction cost.

The Federal Highway Adminstration has published a series of reports describing research conducted to identify problem areas within the US and to develop remedies where feasible (Snethen et al., 1975; Patrick and Snethen, 1976; Snethen, Johnson and Patrick, 1977a, 1977b; Snethen, 1979a, 1979b). These reports describe methods to characterize the potential for volume change, and provide maps showing the occurrence and distribution of expansive soils in the US. Methods are also recommended for minimizing damage from such soils.

3.1.3.6 Land Subsidence

Subsidence is caused by densification of earth materials, collapse of subsurface cavities, plastic outflow of weak materials, and regional downwarps. There are several causes of densification of earth materials. They are withdrawal of ground water or petroleum, irrigation of old mudflows, vibration of granular materials, densification of deltaic deposits, decomposition of organic materials in swamp deposits, artificial compaction of fills and embankments, and surcharging.

Collapse of subsurface cavities may occur in karst topography or because of previous mining activities.

Examples of plastic outflow of weak materials are in fill above peat bogs and recent lake deposits.

Regional downwarps are large scale subsidence basins and are caused by tectonic, glacial or volcanic activity.

Subsidence is a gravity dominated movement so its principle movement is vertical, but there is always lateral strain associated with subsidence, which could cause serious damage to engineered disposal units.

In some areas land subsidence has progressed to the point of equilibrium under existing conditions and any further movement would be relatively insignificant, unless the driving forces changed, such as increased well pumping. Equilibrium would have to be established for the site to be suitable. Subsidence caused by underground cavities can be reduced by grouting the cavities. However, this is an expensive operation and is not recommended if the site can be avoided.

Regional geological data should be carefully examined to identify any areas of possible subsidence and records of any previous mining, oil drilling, or substantial ground water use practices should be investigated. These areas should be avoided, if evidence of significant ongoing subsidence is found.

3.2 Design

3.2.1 Role of Design Features

The role of design features is to complement the natural site characteristics at the disposal site. The degree of reliance that must be placed in the design features will vary from site to site and even within a site. Design features should not be viewed as a means to overcome a site deficiency, unless it can be shown that the design feature will be effective over the entire time of concern. Rather the design features should enhance or improve the performance of a site deemed satisfactory.

Design features include all the components, equipment, and facilities, other than the land itself, used for waste management and disposal at the site. One goal of the design should be to minimize the potential conflicts between construction, operations, and closure activities to ensure compatibility while providing for efficient land use.

Specific features and components were discussed previously.

3.2.2 Assessment of Existing Criteria

The existing criteria for assessment of near-surface disposal site design are contained in 10 CFR 61 Subpart D, paragraph 61.51. Six technical requirements are listed under subparagraph 61.51(a).

The criteria are considered one at a time in the following paragraphs. Additional technical considerations that should be addressed are discussed at the end of the section.

Criterion 10 CFR 61.51 (a)(1) states: "Site design features must be directed toward long-term isolation and avoidance of the need for continuing active maintenance after site closure."

Discussion. The objective of this requirement is technically sound. Major features and components of an EMCB disposal facility that could enhance long-term isolation of wastes and minimize the need for continuing active maintenance have been discussed in the preceding section of this report.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.51 (a)(2) states: "The disposal site design and operation must be compatible with the disposal site closure and stabilization plan and lead to disposal site closure that provides reasonable assurance that the performance objectives of Subpart C of this part will be met."

Discussion. The criterion is directly applicable to the EMCB disposal method. Since this alternative contains multiple individual disposal units associated with a facility, the operations and closure of individual disposal units must be compatible with the site closure and stabilization plan.

This point has been considered and discussed in relation to shallow land burial by the NRC staff (Siefken and others, 1982), Tucker (1983), and Pangburn and Pennifill (1982). No conflicts or differences in design philosophy should occur between shallow land burial or EMCB disposal.

However, while this point may seem to be an obvious requirement, i.e., if the site design, operations, and closure are compatible then the design, operations, and closure of individual disposal units must also be compatible, this may not always be the case.

An example is provided by the French method of backfilling completed tumuli at their earth mounded bunker disposal facility. Backfill is not placed progressively. Rather the backfill is placed after completing waste emplacement, which may take up to 1 year. This practice means that the waste packages are exposed to the atmosphere and workers are exposed to extra risks during the early, perhaps most critical time period. However, the risks are largely offset by their extensive use of concrete embedment and waste packaging.

Therefore, although the criterion is judged to be directly applicable, it is recommended that due consideration be given to the compatibility of the design, operation, and closure of individual units, as well as the overall site.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.51 (a)(3) states: "The disposal site must be designed to complement and improve, where appropriate, the ability of the disposal site's natural characteristics to assure that the performance objectives of Subpart C of this part will be met."

Discussion. This criterion is directly applicable to any alternative disposal method, including EMCBs. In fact, the primary reason for considering any engineered facility for LLW disposal is that it may complement and improve the ability of the disposal site to meet the performance objectives.

Methods and features of an EMCB which could be used to enhance the disposal site's natural characteristics have been discussed in section 2 of this report.

Recommendation. This criterion should be retained as is.

Criterion 10 CFR 61.51 (a)(4) states: "Covers must be designed to minimize to the extent practicable water infiltration, to direct percolating or surface water away from the disposed waste, and to resist degradation by surface geologic processes and biotic activity."

Discussion. This requirement is vital to satisfactory long-term performance of any near surface disposal facility. Again, methods and components which could be used to enhance cover performance have been discussed in section 2. Temporary covers were also recommended to minimize the possibility of runoff and rainfall entering the disposal unit. Also the geochemical compatibility of site soils and construction materials should be assessed.

Recommendation. The criterion should be retained as is. This recommendation is in agreement with the intent of the Task 1 report position. No modification is thought to be necessary to cover the need to assess geochemical compatibility of soil backfill and concrete monoliths and waste packages, as called for in the Task 1 report.

Criterion 10 CFR 61.51 (a)(5) states: "Surface features must direct surface water drainage away from disposal units at velocities and gradients which will not result in erosion that will require ongoing active maintenance in the future."

Discussion. The objective of this requirement is valid. Methods and features for enhancing surface drainage and minimizing erosion and resulting maintenance have been suggested in previous sections of this report. Tucker (1983) also recommends surface grading practices to minimize this problem. He also provides guidance on susceptibility of various soils to erosion and recommends various surface ditch profiles and slopes for reducing erosion of the drain soils.

The primary methods for minimizing erosion are to limit the area over which runoff flows, provide gentle slopes, and channel the runoff into drainage ditches which may be sodded or covered by concrete or other materials to protect them.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.51 (a)(6) states: "The disposal site must be designed to minimize to the extent practicable the contact of water with waste during storage, the contact of standing water with waste during disposal, and the contact of percolating or standing water with wastes after disposal."

Discussion. Again this requirement is valid and achievable. The risk of each of the potential cases of contact of water with wastes can be minimized. Temporary storage areas should be sloped and covered with roofs or temporary storage times should be as short as possible. If drainage layers and pumpable wells are used the contact of standing water with wastes during disposal should be minimal. Disposal operations should cease during rain and snow storms. If use of satisfactory backfill, surface sealants, and cover materials and construction methods are adhered to, the contact of infiltrating water should be minimized.

Recommendation. The criterion should be retained as is.

3.2.3 Suggested Additional Technical Considerations

The need to plan for individual disposal unit closure, as well as site closure, as discussed under 61.51 (a)(2) should be considered.

Also, as stated under 61.51 (a)(4), the need to ensure geochemical compatibility of soil backfill and concrete monoliths and waste packages should be considered.

3.3 Operations and Closure

3.3.1 Importance of Well Planned and Executed Operations and Closure Strategy

The main points to consider in planning for operations and closure of any LLW disposal facility are:

(1) Worker safety with respect to radiological hazards and hazards associated with excavation, construction, and maintenance of the site facilities.

(2) Compatibility of activities to minimize interferences among construction, operations, monitoring, and temporary and final closure.

(3) Avoidance of activities that would lead to long-term active maintenance problems.

(4) Records management and quality control and assurance.

(5) Maintenance of a buffer zone of sufficient lateral and vertical extent such that sufficient space and time would be available to carry out remedial actions should they be required. The remedial action plan should be keyed to minimizing off-site releases of radionuclides during the period of significant hazard.

(6) Efficient land use.

3.3.2 Assessment of Existing Criteria

The 11 existing criteria for evaluation of land disposal facility operation and disposal site closure are listed under 10 CFR Subpart D, paragraph 61.52.

As was done in the previous sections for site suitability and design, each criterion is listed, discussed, and a recommendation is then made to retain the criterion as is, modify the criterion, or not apply it to the evaluation of this method. Additional technical considerations are discussed at the end of this section.

Criterion 10 CFR 61.52 (a)(1) states: "Wastes designated as Class A pursuant to 10 CFR 61.55, must be segregated from other wastes by placing in disposal units which are sufficiently separated from disposal units for the other waste classes so that any interaction between Class A wastes and other wastes will not result in the failure to meet the performance objectives in Subpart C of this part. This segregation is not necessary for Class A wastes if they meet the stability requirements in 10 CFR 61.56 (b) of this part."

Discussion. The rationale behind this requirement is that comingling of structurally unstable Class A wastes with Class B and Class C wastes could lead to differential settlement of the waste packages and the disposal unit cover. Significant differential settlement would, in turn, lead to cracking of the cover and significant infiltration into the disposal unit. Since the potential risks are high the practice should be avoided. Class A wastes should be stabilized before disposal in the same disposal units as B and C wastes. Stabilization and closure of disposal units in which only stable wastes are disposed can be accomplished soon after the units have been filled because long-term subsidence will be minimized if backfill is properly compacted.

Stabilization and closure of units in which unstable Class A wastes are disposed may not be possible until several years have passed. These disposal units will require a higher level of ongoing maintenance during this time.

Recommendation. The criteria should be retained as is. However, stabilization of Class A wastes is highly recommended. Unstable Class A wastes should not be disposed of in EMCBs.

Criterion 10 CFR 61.52 (a)(2) states: "Wastes designated as Class C pursuant to 10 CFR 61.55, must be disposed of so that the top of the waste is a minimum of 5 meters below the top surface of the cover or must be disposed of with intruder barriers that are designed to protect against an inadvertent intrusion for at least 500 years."

Discussion. Class C wastes represent the greatest potential radiological hazard of any waste presently acceptable for near-surface disposal. Consequently, these wastes should be isolated from the biosphere and the inadvertent intruder by a greater distance or barrier. The requirement is valid and can be achieved by deeper disposal of Class C, by the use of durable, intruder resistant packaging, by disposing of Class C only in the bottom of disposal units or with Class B or stabilized Class A wastes stacked above and around the sides of Class C wastes. Significant intruder barriers such as concrete or metal covers could also be used over the disposal units.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.52 (a)(3) states: "All wastes shall be disposed of in accordance with the requirements of paragraphs (a)(4) through (11) of this section."

Discussion. The referenced requirements are discussed individually below.

Recommendation. This umbrella criterion can be retained without impact for any disposal method.

Criterion 10 CFR 61.52 (a)(4) states: "Wastes must be emplaced in a manner that maintains the package integrity during emplacement, minimizes the void spaces between packages, and permits the void spaces to be filled."

Discussion. This requirement has several desirable goals. Rupture of packages during operations would result in higher risks of radiation exposure to workers, and could result in contamination of equipment, areas adjacent to the disposal unit, and even offsite contamination if contaminated equipment leaves the site.

Minimization of voids is the key to minimization of settlement. It also promotes efficient use of disposal space.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.52 (a)(5) states: "Void spaces between waste packages must be filled with earth or other solid material to reduce future subsidence within the fill."

Discussion. Minimization of subsidence will result in greatly reduced long-term maintenance problems, as discussed previously. Suitable materials that can be used for backfilling void spaces include granular soil and concrete. The goal of this criterion is sound and achievable if the right materials and care are used.

Recommendation. The criterion should be retained as is. In the Task 1 report, it was recommended that separate requirements be established for backfilling voids in the monolith and mound portions. Upon reassessment, this is not considered necessary. Backfill requirements can be assessed within the context of the existing criterion.

Criterion 10 CFR 61.52 (a)(6) states: "Waste must be placed and covered in a manner that limits the radiation dose rate at the surface of the cover to levels that at a minimum will permit the licensee to comply with all provisions of 10 CFR 20.105 of this chapter at the time the license is transferred pursuant to 10 CFR 61.30 of this part."

Discussion. This criterion has a valid and achievable goal and is directly applicable to EMCB disposal. Additionally, during the "operational" period of each unit, radiation dosages must also be limited at the surface, and temporary covers or backfill should be placed over high activity wastes during the interim between placement and closure. It should be noted that the waste package and structural features of the disposal unit, e.g., the concrete or soil backfill, would enhance shielding and reduce surface doses.

Placement of Class C wastes on the bottom of the disposal unit and Class B or stabilized Class A above would also reduce surface dose rates.

Recommendation. The criterion should be retained. However, temporary closure should be addressed, as recommended in the Task 1 report, either in the form of regulatory guidance or additional criteria. Modification of 61.52 (a)(6) may be appropriate for this purpose.

Criterion 10 CFR 61.52 (a)(7) states: "The boundaries and locations of each disposal unit (e.g., trenches) must be accurately located and mapped by means of a land survey. Near-surface disposal units must be marked in such a way that the boundaries of each unit can be easily defined. Three permanent survey marker control points, referenced to United States Geological Survey (USGS) or National Geodetic Survey (NGS) survey control stations, must be established on the site to facilitate surveys. The USGS or NGS control stations must provide horizontal and vertical controls as checked against USGS or NGS record files."

Discussion. This requirement is necessary to ensure positive location of disposal units in case remedial action becomes necessary and to reduce the likelihood of inadvertent intrusion. These goals are desirable and technically achievable, using standard surveying methods.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.52 (a)(8) states: "A buffer zone of land must be maintained between any buried waste and the disposal site boundary and beneath the disposed waste. The buffer zone shall be of adequate dimensions to carry out environmental monitoring activities specified in 10 CFR 61.53(d) of this part and take mitigative measures if needed."

Discussion. This requirement was specified to ensure that adequate space and time would be available to detect and correct any performance deficiencies, i.e., radionuclide migration, before they leave the site boundary. A fixed distance was not specified because of the variable relationship between radionuclide and ground-water travel times and site soil characteristics, primarily hydraulic conductivity and adsorption capacity. An additional consideration is to ensure that sufficient space exists between and around disposal units to carry out normal operations and closure activities. This is a practical requirement that can be easily implemented.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.52 (a)(9) states: "Closure and stabilization measures as set forth in the approved site closure plan must be carried out as each disposal unit (e.g., each trench) is filled and covered."

Discussion. As discussed by Pangburn and Pennifill (1982), the purpose of this requirement is primarily to minimize the number and extent of activities to be performed at the time of site closure. By closing and stabilizing disposal units as they are completed, the operator will be able to focus final closure and stabilization efforts on known problem areas. Moreover, early closure and stabilization will help to minimize infiltration, lower dose rates to site personnel and protect waste package integrity. Early closure of filled disposal units also provides valuable experience from which to fine-tune final closure methods. Finally, if completed disposal units are not promptly closed and stabilized, the probability of achieving long-term isolation and avoidance of the need for continuing active maintenance could be compromised. Therefore, an applicant should provide, as part of the application, a closure and stabilization plan to be implemented upon completion of any given disposal unit. To assure closures within a reasonable time period, a construction sequencing plan with projected future waste quantities and categories should be submitted to indicate facility operation and closure time periods.

Disposal units that have been closed should be periodically inspected to ensure satisfactory performance. Such inspections should identify areas of erosion, cover cracking and settlement, ponding, and condition and extent of vegetation. Areas of lush vegetation should be checked to determine if these areas are wetter than adjacent areas.

Problems noted should be accompanied by plans for remedial actions. Subsequent inspections should note whether such remedial actions were undertaken and whether the noted problem has been corrected or still exists.

Procedures similar to this have been followed for decades by the Corps of Engineers in their periodic inspections and evaluations of locks and dams and other civil works.

Recommendation. The criterion should be retained as is. In the Task 1 report, a recommendation was made to require closure of each component of a disposal unit as it was filled, that is the monolith compartments and mounds. This objective can be achieved within the framework provided by the existing criterion.

Criterion 10 CFR 61.52 (a)(10) states: "Active waste disposal operations must not have an adverse effect on completed closure and stabilization measures."

Discussion. This requirement seeks to ensure that active operations do not result in damage to completed disposal units. Satisfaction of this requirement is achievable through advance planning of both normal operations and contingencies. Simple examples would include allowing enough room between disposal units for normal equipment movements without endangering adjacent units, temporary storage of excavated materials, and monitoring points.

Sufficient room should be provided between arrays of disposal units to allow for surface water management features and closure of completed units.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.52 (a)(11) states: "Only wastes containing or contaminated with radioactive materials shall be disposed of at the disposal site."

Discussion. This criterion is directly applicable to the EMCB disposal alternative. However, it may not go far enough in stating what may not be disposed of, e.g., hazardous or toxic wastes that are slightly radioactive. This issue is considered within the criteria for waste characteristics, 10 CFR section 61.56. However, the intent of paragraph 61.56 is to facilitate handling and to ensure protection of the health and safety of workers. In addition, the potential for damage to the engineered disposal unit from the contained wastes, e.g. chemical attack, should be considered.

Recommendation. The criterion should be retained as is, but the additional concern discussed above should be addressed.

3.3.3 Suggested Additional Technical Considerations

Except for the comments and suggestions made in the discussion of each existing criterion, no specific additional technical considerations are thought to be necessary.

3.4 Monitoring

3.4.1 Role of Monitoring

The overall objective of monitoring any low-level radioactive waste disposal facility is to provide reasonable assurance that the performance objectives are being met. Monitoring is considered to include the systematic collection, analysis, and interpretation of data related to the radiological, chemical, physical, and environmental properties of specific media in the vicinity of a LLW site during all phases of site life.

Monitoring should also include development of a plan of action to be implemented when one or more of the monitored parameter values exceeds a specified preestablished limit during or after the operations period (Lutton and others, 1983).

In addition to determining compliance with the performance objectives established in 10 CFR 61, the monitoring program should also:

a. Aid in site characterization.

b. Establish a statistical data base for background values of parameters of concern.

c. Provide a data base useful in the selection and verification of a site model.

d. Provide a method for determining when corrective actions are necessary, i.e., a plan of action to be implemented when the values of one or more parameters exceed a specified action level.

The monitoring program extends from the preoperational site investigation program through the operation period, and for some time after closure.

Lutton and others (1982a, 1982b, and 1983) in a series of three reports (NUREG/ CR-2700, NUREG/CR-3038, and NUREG/CR-3164) described the parameters which needed to be monitored, test methods and equipment required to measure these parameter values, and a comprehensive subsurface monitoring program that could achieve the intended objectives at LLW disposal sites.

Sedlett and others (1982) have also developed a handbook for environmental monitoring of LLW disposal sites.

Rogers, Sutherland, and Adams (1982) have developed a handbook for LLW disposal that discusses specific objectives and gives examples of monitoring techniques suitable for shallow land burial. Many of these recommendations would be equally applicable to an EMCB disposal facility.

It is not the purpose of this report to make recommendations concerning a specific program for monitoring disposal facilities.

Such a program must be site specific and tuned to the design and plans for operation and closure of the facility.

The above references, NRC staff position papers, and the existing monitoring criteria, along with the recommendations in this report should provide adequate basis for development of specific monitoring programs.

It should be noted that, if the disposal facility is properly sited, designed, and operated, the major function of the monitoring program is to provide reassurance of satisfactory performance and safety of the facility.

3.4.2 Assessment of Existing Criteria

The existing criteria for assessment of environmental monitoring of land disposal of LLW are contained in paragraph 61.53 of 10 CFR 61 Subpart D. These four criteria are listed in subparagraphs 61.53(a)-(d) and are listed and discussed individually below.

Additional technical considerations are discussed at the end of this section.

Criterion 10 CFR 61.53(a) states: "At the time a license application is submitted, the applicant shall have conducted a preoperational monitoring program to provide basic environmental data on the disposal site characteristics. The applicant shall obtain information about the ecology, meteorology, climate, hydrology, geology, geochemistry, and seismology of the disposal site. For those characteristics that are subject to seasonal variation, data must cover at least a twelve month period."

Discussion. This requirement is basic to the establishment of site suitability, design considerations, and operations and closure plans. While the specific information that is to be collected and its relative importance can be expected to vary, as well as the use to which it is put, the need for a systematic program is absolute.

For example, it can be reasonably concluded that ground-water aging is unnecessary at an arid site where disposal will take place far above the water table. It should be recognized that one year may be an insufficient length of time over which to document variations of some data of importance, such as water table fluctuations. Existing records should be used to supplement analyses based on such relatively short-term data collection periods.

Recommendation. This criterion should be retained as is.

Criterion 10 CFR 61.53 (b) states: "The licensee must have plans for taking corrective measures if migration of radionuclides would indicate that the performance objectives of Subpart C may not be met."

Discussion. This requirement is a valid one and suggests the need for further requiring that the licensee have on file plans for specific actions if detected concentrations or rates of radionuclide migration exceed preestablished limits.

The action plan should indicate methods and equipment to be used and the time table for mobilization. This requirement is keyed to the requirement for and size of the buffer zone, so that reaction and implementation of the planned action can be effected before radionuclides migrate beyond the site boundary.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.53 (c) states: "During the land disposal facility site construction and operation, the licensee shall maintain a monitoring program. Measurements and observations must be made and recorded to provide data to evaluate the potential health and environmental impacts during both the construction and the operation of the facility and to enable the evaluation of long-term effects and the need for mitigative measures. The monitoring system
must be capable of providing early warning of releases of radionuclides from the disposal site before they leave the site boundary."

Discussion. The objective of this requirement is to ensure the site continues to perform satisfactorily after closure and to provide a basis for checking on any previous problem areas, while allowing sufficient time to fix any observed deficiencies.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.53 (d) states: "After the disposal site is closed, the licensee responsible for postoperational surveillance of the disposal site shall maintain a monitoring system based on the operating history and the closure and stabilization of the disposal site. The monitoring system must be capable of providing early warning of releases of radionuclides from the disposal site before they leave the site boundary."

Discussion. The objective of this requirement is to ensure the site continues to perform satisfactorily after closure and to provide a basis for checking on any previous problem areas, while allowing sufficient time to fix any observed deficiencies. This is a valid requirement.

Recommendation. The criterion should be retained as is.

3.4.3 Suggested Additional Technical Requirements

In addition to an approved monitoring program and plans for mitigative measures, it is recommended that the licensee be required to provide a disposal plan for water and other materials that have been sampled and tested.

It is further recommended that each disposal unit be monitored individually so that any problems that develop can be quickly traced to their origin and corrected.

4. CONCLUSIONS AND RECOMMENDATIONS

The only experience with the earth mounded concrete bunker, as narrowly defined within this study, has been that gained since 1969 in France at the Centre de la Manche.

Variations of this concept were tested by ERDA, as reported herein, and bunker type storage facilities have been used in Canada. However, the primary experience is that gained at the Centre.

The experience gained at this site, together with improvements in operations and planning made since ANDRA was established in 1979, indicates that this disposal method can satisfactorily meet the performance objectives of 10 CFR Part 61 Subpart C.

To meet these performance objectives, a systems approach is required for site characterization, design, construction, operations, closure, and monitoring. Favorable and unfavorable site characteristics must be identified and the impacts of unfavorable characteristics quantified. Design features should complement the site's favorable qualities and improve the less favorable qualities. Strict quality control and assurance must be followed during construction to achieve the design objectives. Operations and closure must be carefully planned and implemented to minimize interferences and long-term active maintenance. Progressive closure of individual disposal units is recommended to decrease the scope of activities required at the end of the operations period, to promote early stabilization of the site, and to reduce risks of harmful exposures to operating personnel.

If such a system is followed, an EMCB facility can be built using commercially available equipment and standard construction industry practices that could meet or exceed the performance objectives.

Some of the features and components that could enhance long-term performance have been described in this report, including the use of pervious backfill around the monoliths to promote drainage and extension of the surface low permeability barrier or sealant beyond the boundaries of the monoliths out to the surface drainage ditches to minimize infiltration. Monitoring of individual disposal units was also recommended.

An EMCB disposal facility is accurately defined as a near-surface disposal method. It has been determined herein that the method is amenable to evaluation using the existing technical criteria of Subpart D of 10 CFR Part 61.

Minor qualifications of existing criteria and additional technical issues considered appropriate for EMCBs are discussed in Part 3. These considerations may be addressed through guidance within the context of existing criteria or at the discretion of the NRC, promulgation of additional criteria.

Those issues recommended for consideration are summarized below.

In the determination of site suitability, the occurrence and potential impacts of dispersive soils, expansive soils, liquefiable soils, corrosive soils, and areas undergoing land subsidence, or solution-cavity formation should be assessed.

The chemical compatibility of construction materials, site soils, and waste form should be considered.

Temporary closure and individual disposal unit closure should be addressed, in addition to overall site closure, through submittal of a detailed plan for operations and closure of the facility. This plan should address disposal of soil, water, and other sampled materials found to be contaminated by radioactivity.

An issue not fully addressed by this study that deserves further investigation is long-term durability and performance of concrete and other construction materials. Appendix A is a first step in this direction for concrete, in that the major factors that impair long-term durability are identified and design and construction practices to minimize their impacts are recommended. The authors are aware of other limited research in this area but recommend that this area of research be emphasized and expanded. Materials research has significant potential payoffs not only for engineered disposal facilities, but also for waste packaging, transport, and storage, prior to disposal.

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GLOSSARY

ACTIVE MAINTENANCE: Any significant remedial activity needed during the period of institutional control to maintain a reasonable assurance that the performance objectives in 10 CFR 61.41 and 61.42 are met. Such active maintenance includes ongoing activities such as the pumping and treatment of water from a disposal unit or one-time measures such as replacement of a disposal unit cover. Active maintenance does not include custodial activities such as repair of fencing, repair or replacement of monitoring equipment, revegetation, minor additions to soil cover, minor repair of disposal unit covers, and general disposal site upkeep such as mowing grass.

ACTIVITY: A measure of the rate at which a material is emitting nuclear radiations; usually given in terms of the number of nuclear disintegrations occurring in a given quantity of material over a unit of time; the standard unit of activity is the curie (Ci), which is equal to 3.7×10^{10} disintegrations per second.

AGREEMENT STATES: Any States with which the Commission or the AEC has entered into an effective agreement under subsection 274b of the Atomic Energy Act of 1954. A Nonagreement State is any other State. (10 CFR 150.3)

AQUICLUDE: A formation which, although porous and capable of absorbing water, does not transmit it at rates sufficient to furnish an appreciable supply for a well or spring. (ASTM STP 746)

AQUIFER: Geologic stratum or set of beds with relatively high transmissivity and carrying ground water in quantities to make exploitation for consumption economically feasible.

AUGERED HOLES: Cylindrical, near-vertical holes or shafts excavated by spiral augers or other methods.

BACKGROUND RADIATION: Radiation in the environment from naturally occurring radioactive elements, cosmic radiation, and fallout from man's activities such as nuclear weapons testing.

BUFFER ZONE: A portion of the disposal site that is controlled by the licensee and that lies under the disposal units and between the disposal units and the boundary of the site.

CURIE (Ci): A unit of radioactivity defined as the amount of a radioactive material that has an activity of 3.7×10^{10} disintegrations per second (d/s); millicurie (mCi) = 10^{-3} curie; microcurie (Ci) = 10^{-6} curie; nanocurie (nCi) = 10^{-9} curie; picocurie (pCi) = 10^{-12} curie; femtocurie (fCi) = 10^{-15} curie.

DECONTAMINATION: The selective removal of radioactive material from a surface or from within another material.

DISPOSAL SITE: That portion of a land disposal facility which is used for disposal of waste. It consists of disposal units and a buffer zone.

DISPOSAL UNIT: A discrete portion of the disposal site into which waste is placed for disposal. For current near-surface disposal the unit is usually a trench.

ENGINEERED BARRIER: A man-made structure or device that is intended to improve a land disposal facility's ability to meet the performance objectives in 10 CFR Part 61, Subpart C.

ENGINEERED DISPOSAL: As used in this report, the disposal of radioactive wastes, usually in suitable sealed containers, in any of a variety of structures especially designed to protect them from water and weather and to prevent leakage to the biosphere by accident or sabotage.

ENVIRONMENTAL SURVEILLANCE: Monitoring of the impact on the surrounding region of the discharges from industrial operations, forest fires, storm runoff, or other natural or man-induced events.

EXPOSURE: A measure of the ionization produced in air by X or gamma radiation. It is the quotient of (1) the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by (2) the mass of the air in the volume element. The special unit of exposure is the Roentgen. (Radiological Health Handbook, U. S. Dept. of HEW). Acute exposure generally refers to a high level of exposure of short duration; chronic exposure is lower-level exposure of long duration.

GROUND WATER: Water that exists or flows below the ground surface (within the zone of saturation).

GROUT: Fluid or semifluid material, often containing Portland cement, which may be pumped or poured into earth strata and by setting up into a solid state, provides mechanical stabilization or water flow control.

HALF-LIFE: The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billons of years. After a period of time equal to 10 half-lives, the radioactivity of a radionuclide has decreased to 0.1 percent of its original level.

HAZARDOUS WASTE: Those wastes designated as hazardous by Environmental Protection Agency regulations in 40 CFR Part 261.

HYDROGEOLOGY: The study of ground water, with particular emphasis on its chemistry, mode of migration, and relation to the geologic environment. (Davis and De Wiest, 1966).

HYDROGEOLOGIC UNIT: Any soil or rock unit or zone which by virtue of its porosity or permeability, or lack thereof, has a distinct influence on the storage or movement of ground water.

IN SITU: In the natural or original position; used to refer to inplace experiments at a storage or disposal site.

INADVERTENT INTRUDER: A person who might occupy a disposal site after closure and engage in normal activities, such as agriculture, dwelling construction, or other pursuits, in which the person might be unknowingly exposed to radiation from the waste.

INTRUDER BARRIER: A sufficient containment of the waste that inhibits human contact with waste and helps to ensure that radiation exposures to an inadvertent intruder will meet the performance objectives set forth in 10 CFR 61; or engineered structures that provide equivalent protection to the inadvertent intruder.

ION: Atomic particle, atom, or chemical radical bearing an electrical charge, either negative or positive.

ION EXCHANGE: A reversible interchange that takes place between ions of like charge, usually between ions present on an insoluble solid and ions in a solution surrounding the solid. An important process in both fundamental and industrial chemistry.

ION-EXCHANGE RESIN: An insoluble polymerized electrolyte that contains either acidic groups for exchanging cations or basic groups for exchanging anions. It contains large, high-molecular-weight ions of one charge and small, simple ions of the opposite charge. The small ions undergo exchange with ions in solution.

IONIZING RADIATION: Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.

ISOTOPES: Nuclides having the same number of protons in their nuclei, and hence the same atomic number, but differing in the number of neutrons, and therefore in the mass number. Identical chemical properties exist between isotopes of a particular element.

KARST: Surface or subsurface rock mass conditions characterized by solution-formed caverns, cavities, open joints, pinnacles, and depressions of a highly irregular form. Almost exclusively applied to carbonate lithologies, e.g., limestone.

LAND DISPOSAL FACILITY: Land, buildings, and equipment intended to be used for the disposal of radioactive wastes into the subsurface of the land. A geologic repository as defined in 10 CFR 60 is not considered a land disposal facility. (10 CFR 61.2)

LEACHING: The process of extracting a soluble component from a solid by the percolation of a solvent (e.g., water) through the solid.

LIQUEFIABLE: Susceptible to near-total loss of shear strength and bearing capacity duing seismic disturbances; used with reference to soils.

LITHOLOGY: The character of a rock formation or of the rock found in a geological area or stratum expressed in terms of its structure, mineral composition, color, and texture.

LOW-LEVEL RADIOACTIVE WASTE (LLW): Radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or by-product material as defined in section 11e. (2) of the Atomic Energy Act of 1954. (P.L. 96-573) Radioactive wastes containing source, special nuclear, or by-product material that are acceptable for disposal in a land disposal facility (10 CFR 61.2) For explanation of Class A, Class B, and Class C LLW, see 10 CFR 61.55 and 61.56.

NEAR-SURFACE DISPOSAL FACILITY: A land disposal facility in which radioactive waste is disposed of in or within the upper 30 meters of the earth's surface.

PERMEABILITY: The capacity of a porous medium to conduct liquids or gases.

PIEZOMETER: An instrument for measuring pressure head in ground water. In an unconfined aquifer with a free water table a piezometer is frequently an open-bottomed monitor well extending below that water table.

PSYCHROMETER: Device used for measuring the amount of water vapor in air; e.g., a hygrometer.

PYROPHORIC: Igniting spontaneously. A pyrophoric liquid is any liquid that ignites spontaneously in dry or moist air at or below 130°F (54.5°C). A pyrophoric solid is any solid material, other than one classed as an explosive, which under normal conditions is liable to cause fires through friction, retained heat from manufacturing or processing, or which can be ignited readily and when ignited burns so vigorously and persistently as to create a serious transportation, handling, or disposal hazard. Included are spontaneously combustible and water-reactive materials.

RAD: The unit of absorbed dose equal to 100 ergs per gram or 0.01 joule per kilogram.

RADIOACTIVITY: The property of certain nuclides of spontaneously emitting particles or gamma radiation, or of emitting X radiation following orbital electron capture, or of undergoing spontaneous fission. (Radiological Health Handbook, U. S. Dept. of HEW)

REM: A special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor, and any other necessary modifying factors. (Radiological Health Handbook, U. S. Dept. of HEW) The dosage of any ionizing radiation that will cause the same amount of biological injury to human tissue as one roentgen of X-ray or gamma-ray dosage. (Webster's Third New International Dictionary) (1 millirem = 0.001 REM)

REPOSITORY: A term generally applied to a facility for the disposal of radioactive wastes, particularly high-level waste and spent fuel.

ROENTGEN: The special unit of exposure. One roentgen equals 2.58×10^{-4} coulomb per kilogram of air. (Radiological Health Handbook, U. S. Dept. of HEW) The international unit of X radiation or gamma radiation that is the amount of radiation producing, under ideal conditions in one cubic centimeter of air at 0°C and 760 mm Hg pressure, ionization of either sign equal to one electrostatic unit of charge. (Webster's Third New International Dictionary)

SEISMIC: Of, pertaining to, of the nature of, subject to, or caused by an earthquake.

SITE CLOSURE AND STABILIZATION: Those actions that are taken upon completion of operations that prepare the disposal site for custodial care and that assure that the disposal site will remain stable and will not need ongoing active maintenance.

SUBSIDENCE: Sinking or depression of the ground surface; generally due to loss of subsurface support.

SURVEILLANCE: Observation of the disposal site for purposes of visual detection of need for maintenance, custodial care, evidence of intrusion, and compliance with other license and regulatory requirements.

TECTONIC: Of or relating to the deformation of the earth's crust, the forces involved in or producing such deformation, and the resulting rock structures and external forms.

TILEHOLE: A form of augered hole which is lined with ceramic, concrete, or metal fabrications and may be used for retrievable radioactive waste storage.

TRANSMISSIVITY: A property of an aquifer; the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

UNSATURATED ZONE: The zone of soil or rock between the ground surface and the water table; also termed the vadose zone.

VAULT: An artificial enclosed space covered by an overhead structure; especially a passage or room used for storage or safekeeping.

VULCANISM: The processes by which magma (molten rock material within the earth) and its associated gases rise into the earth's crust and are extruded onto the earth's surface and into the atmosphere.

WATER TABLE: The surface within an unconfined aquifer between the zone of saturation and the zone of aeration; that surface of a body of unconfined ground water at which the pressure is equal to atmospheric pressure.

APPENDIX A

Long Term Performance and Durability of Portland Cement Concrete as the Building Material for Engineered Facilities

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CTD/SL

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1. Introduction

The disposal of low-level radioactive waste in engineered facilities requires an in-depth evaluation of the construction materials used to attempt the prediction of the service life of structures used for this disposal. This section of the report addresses the parameters to be considered in the use of reinforced portland-cement concrete as the building material for disposal vault or other engineered facilities.

Predicting behavior and durability of materials and structures for long periods of time, such as 500 years, has, as its foundation, extrapolation of short-term data, which in many cases may lack a proper rationale. The ancient Roman engineers and builders produced constructions that we can examine today but passed on very little written narrative of how they designed and constructed their projects (Malinowski, 1979). Present-day efforts to reconstruct, by deduction, the formulation of concrete mixtures, the identification of the exact materials, and a definite statement as to construction methodology have met with only slight success (Malinowski, 1979 and Roy and Langton, 1983). However, these studies permit better understanding of the aging process that may be expected for certain materials.

Predicting the long-term stability and performance of materials such as cements, mortars, and concrete may be approached in two ways: (1) examination of the physical performance of old structures and (2) interpretation of the chemical activity of the observed durability of old cementing materials.

Long-term performance is an approximate synonym of durability, and the factors which impair such durability will determine its long-term performance.

Generally, concrete durability depends on its porosity, permeability, absorptivity, capillarity, response to imposed stresses, and bond of the components.

2. Factors that Impair the Integrity of Concrete

The structural integrity of a reinforced portland-cement concrete structure is a function of the quality and durability of the structure in response to the applied loads and stresses and of the durability and quality of the concrete contained in the structure. Durability of a structure has been defined (ASTM, 1977) as "the safe performance of a structure or a portion of a structure for the designed life expectancy." Durability of portland cement concrete has been defined (ACI, 1977) as "its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration." It is essential to recognize the main types of concrete deterioration and then address measures and techniques that can be employed to protect against these attacks.

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American Concrete Institute (ACI) Committee 201 (ACI, 1977) has listed five important causes of concrete deterioration as: (1) freezing and thawing, (2) aggressive chemical exposure, (3) abrasion, (4) corrosion of steel and other metals embedded in concrete, and (5) chemical reactions of aggregates. The following paragraphs define and discuss these causes.

2.1 Freezing and Thawing

Freezing and thawing damage is the phenomenon that occurs when critically saturated concrete is subjected to freezing and thawing. Hardened cement paste and aggregate have very different behavior responses to freezing and thawing and therefore should be considered separately.

2.1.1 Freezing and thawing of cement paste. The porosity of cement paste, in fairly dense and well consolidated concrete, is between 30 percent and 50 percent. This pore structure becomes reservoirs for water which can freeze and cause disruptive and damaging action. The research done by Powers (1945, 1954, 1955), Helmuth (1960), Collins (1944), and Litvan (1974) produced what is generally accepted as the mechanisms taking place during freezing, though each researcher's findings differ somewhat in detail. It is now believed by many researchers that osmotic pressure of the freezing water in the pores and connecting capillaries causes most of the frost damage in cement paste (ASTM, 1977). The pressures generated by this mechanism cause the paste to fail, which in turn, causes the concrete mass to fail.

Generally, it is agreed (and has been demonstrated time and again) that air entrainment of cement paste can produce a paste that will not be affected by freezing and thawing provided sufficient hydration of cement has taken place before the paste is allowed to freeze while critically saturated. Air entrainment produces a pore distribution system, with appropriate distances between pores, which will accommodate ice movement and pressures.

2.1.2 Freezing and thawing of aggregate particles. As just stated, air entrainment can prevent damage in cement paste, but the freezing action in aggregate particles must also be considered so as to produce a concrete that will be free of damage.

The basic mechanism is called "the hydraulic pressure theory (ASTM, 1977)." Powers (1945) found that the pores of rocks, which are often larger than paste pores, if water filled, expel water during freezing and thereby produce a hydraulic pressure which can cause failure.

In addition, Verbeck and Landgren (1960) found that in coarse aggregate from any given natural rock, there is a critical size below which, if unconfined by cement paste, the material can be frozen without damage.

The overall effect on a concrete composed of sound aggregate and paste of appropriate maturity which has an appropriate air-entrained void system characterized by a spacing factor (maximum distance from any point in the paste to the periphery of a nearby air void) of less than 0.008 in. is one in which no destructive stresses are produced during freezing.

2.2 Aggressive Chemical Exposure

Concrete of good quality will perform satisfactorily when exposed to many chemicals. There are, however, some chemical environments under which the useful life of concrete will be short.

Table 1 lists certain chemicals which attack concrete and recommendations for preventative or remedial protection (Highway Research Board of the National Academy of Sciences, 1966).

Chemical attack on concrete is generally the result of exposure to sulfates or acids, and these are discussed below.

Sulfate attack is a particular problem in arid areas, such as the northern Great Plains area and parts of the western United States. Sulfates such as those found in soils and groundwaters near concrete structures can attack concrete. In the presence of moisture, an expansive reaction takes place between the tricalcium aluminate (C_3A) phase of portland cement and sulfates to produce calcium sulphoaluminate which will cause disruption of concretes. If the C_3A content is lowered during burning of the cement clinker by converting it to tetracalcium alluminoferrite (C_4AF), which is not so suceptible, this produces an effective means of combating sulfate attack.

Type V cement which may not contain more than 5 percent by weight of C_3A, has been found to perform satisfactorily in severe sulfate exposures. Type II cement may not contain more than 8 percent by weight of C_3A and provides moderate sulfate resistance.

In general, portland cement is not acid resistant, but it can withstand weak acids (pH greater than 4.0). Water draining from mines or landfills, some industrial water, and falling rain may contain or form acids which attack concrete. Also, sulfuric acid, carbonic acid, and sulfates are common in ground-water, which could cause corrosion of embedded steel and sulfate attack in concrete.

Acid attack, with the attendent resulting deterioration, is characterized by a chemical reaction between the acid and the calcium hydroxide of the hydrated portland cement. This results in the formation of water-soluble calcium compounds. These in turn are leached away. This total mechanism destroys the binding ability of the cement paste.

Table 1

Certain Chemicals Harmful to Concrete (Effects and Remedies)

Substance	Effect	Remedy
Acetic acid	Causes slow disintegration	Use heavy duty floors with bituminous or polysulfide coatings
Calcium sulfate	Because of limited solubility, attack is less than other sulfates	Use epoxy, rubber, or bituminous coatings: use high quality concrete with high cement factor and air entrainment
Carbon dioxide	No damage to mature concrete, but can dissolve in water to form carbonic acid	Use surface hardeners and coatings: properly vent combustion heaters when placing concrete in heated enclosure
Carbonic acid	Very corrosive to lean mixtures; slowly disintegrates better quality concrete	Use dense, impermeable concrete with high cement factor: use epoxy, neoprene, or vinyl coatings
Fats and oils	Attack varies, depending on concentration of fatty acids and viscosity of oils	Use low water-cement ratio; dense, impermeable concrete; use surface hardeners (Magnesium or zinc flurosilicate), oil-insoluble resin
Hydrobromic acid, hydrochloric acid	Constant contact by strong solution destroys concrete; weak solutions attack slowly	Use protective coatings per ACI 515
Hydrogen sulfide	Sulfuric acid is produced in moist, oxidizing environments, which causes slow disintegration	Use concrete of low permeability; use coatings of polyester, neoprene or epoxy
Iron sulfide	Slow disintegration of low quality concrete if substance contains ferric sulfate	Use good quality concrete; use epoxy, chlorosulfonated polyethylene, or polyester coatings

Table 1 (Continued)

Substance	Effect	Remedy
Magnesium sulfate	0.5% solution (or more) aggressively attacks concrete with low sulfate resistance, causes disruptive expansion	Use high quality air-entrained concrete with high cement factor; use epoxy, rubber, or bituminous coatings
Nitric acid	Constant contact of strong solution destroys concrete	Use protective coatings per ACI 515
Sodium carbonate in solution	Does not affect mature concrete but causes fresh concrete to deteriorate	Protect fresh concrete from contamination
Sodium chloride	Corrodes reinforcing steel which can damage concrete member	Avoid use or presence of substance
Sodium sulfate	0.5% solutions (and greater) strongly attacks concrete of inadequate sulfate resistance	Use high quality air-entrained concrete with high cement factor; use bituminous, rubber, or epoxy coatings
Sulfur dioxide	Dry gas combined with moisture from acids cause long-term deterioration	Use vinyl, epoxy, or chlorinated rubber coatings
Sulfuric and sulfurous acids	Constant contact with strong solutions destroys concrete	Use protective coatings per ACI 515

2.3 Abrasion

Abrasion is the wearing away of a concrete surface by rubbing and friction (ACI, 1967). To consider several mechanisms of abrasion, Prior (1966) has recommended four classifications of abrasion:

(1) Wear on concrete floors (foot traffic, light trucking, skidding, scraping, or sliding of objects on the surface).

(2) Wear on concrete roadways (automobiles with studded tires or chains, heavy trucks).

(3) Erosion in hydraulic structures (waterborne abrasive materials).

(4) Wear on water-carrying systems composed of concrete (high velocities and negative pressures).

Abrasion is a physical wearing away or breaking off of material on the surface of the concrete by the abrading agent. The factors, therefore, which affect the abrasion resistance of concrete to a given abrading agent are: compressive strength, aggregate properties, finishing methods, use of toppings or coatings, and curing. Therefore, higher compressive strength results in greater abrasion resistance; harder coarse and fine aggregate results in higher resistance; properly timing the finishing operations and producing a smooth, dense surface gives higher resistance; application of metallic or nonmetallic coatings to toughen the surface gives higher resistance; and, use of proper curing agents for the required time gives a higher resistance.

2.4 Reactive Aggregates

No aggregates should be considered completely chemically inert. Some of the chemical reactions can be beneficial but others can cause disruptive damage such as abnormal expansion, cracking, and loss of strength (Woods, 1968).

The most predominant harmful reaction is "alkali-silica reaction" and is defined as the reaction between hydroxyl ions associated with the dissolution of the cement alkalies (Na_2O and K_2O) and certain siliceous constituents that may be present in aggregates. This disruption is characterized by expansion and severe cracking of the concrete structure.

Another form of reaction is that between the hydroxyl ions associated with dissolution of the cement alkalies and certain carbonate rocks, usually argillaceous dolomitic limestones. The disruptive damage is usually characterized by expansion, cracking, and aggregate degradation.

Other types of chemical reaction include oxidation or hydration of certain unstable mineral oxides, sulfates, or sulfides that occur after the aggregate has been incorporated into the concrete (Highway Research Board of the National Academy of Sciences, 1966).

All of these reactions usually result in such disruptive damage that the deteriorated concrete must be removed and replaced by sound concrete of better quality.

Table 2 is a summary of the deleterious aggregates discussed herein, derived from ASTM (1977).

2.5 Corrosion of Embedded Material

For corrosion of steel embedded in concrete to occur, the following conditions must all be met: (1) the provision of an anode and cathode, (2) the maintenance of an electrical circuit, (3) the presence of moisture, and (4) the presence of oxygen (Mindness and Young, 1981). Under most conditions, good quality concrete provides adequate protection of embedded steel against corrosion. This is due to the high alkalinity of the concrete (pH of about 12 to 12.5) which causes a passive oxide film that prevents corrosion to form on the surface of the steel. The degree to which concrete will provide satisfactory protection is in most instances a function of the quality of the concrete, the depth of concrete cover, and the degree to which good practices are followed throughout the entire construction operation (ACI, 1979).

The quality characteristic of concrete includes low permeability and proper mixture proportions. The permeability of concrete is a major factor affecting the process of corrosion of embedded materials. Low water-cement ratio with well-graded coarse and fine aggregates produce less permeable concrete and thus provide greater assurance against corrosion. Water-cement ratios should not exceed 0.40 for concrete exposed to sea or brackish water, or in contact with more than moderate concentrations of chlorides at the water or ground line. If the water-cement ratio is raised to 0.45, the concrete cover over the steel should be increased 1/2 in. Studies of durability of concrete (seawater exposure) showed that cements containing 5 to 8 percent tricalcium aluminate (C_3A) showed less cracking due to steel corrosion than cements with a C_3A content less than 5 percent (Verbeck, 1968).

Permeability is reduced by increased hydration of the cement. Concrete should be cured properly until at least 90 percent of the design strength has developed.

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Table 2

Partial List of Deleterious Aggregates

Andesites and tuffs
Chalcedonic cherts
Dacites and tuffs
Fractured, strained, and inclusion-filled quartz and quartzites
Opaline cherts
Opaline concretions
Phyllites
Quartzose cherts
Rhyolites and tuffs
Siliceous dolomites
Siliceous limestones
Siliceous shales

Concrete cover over reinforcing steel should be adequate. In a well-cured concrete with low water-cement ratio, the depth of carbonation (calcium hydroxide is converted to calcium carbonate by atmospheric carbonation which destroys protective oxide film on the surface of the steel) is unlikely to exceed 25 mm, and therefore, a concrete cover of 25 to 40 mm over reinforcing bars should be adequate in most instances (Mindness and Young, 1981). Where more severe conditions of exposures are encountered or concrete with fairly high permeability is used, the cover should be increased at least 50 mm (Mindness and Young, 1981). Protection against penetration of salts to reinforcing steel in seawater exposure is 3 in., while the American Association of State Highway and Transportation Officials (AASHTO) recommends 4 in. except for precast piles.

In addition, other practices have to be followed to minimize corrosion. These are good concreting practices (workmanship), good drainage, and good specifications and inspection.

Good workmanship is a most important factor in securing uniform concrete of low permeability. This includes good consolidation and finishing practices, and precaution against segregation.

In areas of severe exposures, particular attention should be given to design details dealing with drainage to insure that the water will drain.

The passive oxide film on steel can be destroyed by chloride ions. Chlorides may enter the concrete from three major sources: (1) admixtures ($CaCl_2$), (2) deicing salts, and (3) seawater. ACI Committee 201 (ACI, 1977) suggests the following limits for chloride ion (Cl-) in concrete prior to service exposure, expressed as a percent by weight of cement.

1.	Prestressed concrete	0.06 percent
2.	Conventionally reinforced concrete in a moist environment and exposed to chloride	0.10 percent
3.	Conventionally reinforced concrete in a moist environment but not exposed to chloride	0.15 percent
4.	Above ground building construction where the concrete will stay dry (does not include locations where the concrete will be occasionally wetted--such as kitchens, parking garages, and waterfront structures)	No limit for corrosion

These limits should be applied with good judgement because other factors such as moisture and oxygen are necessary for electrochemical corrosion.

3. Recommendations for Minimizing Adverse Effects on Long Term Durability of Concrete

The following practices and precautions are recommended to provide durable concrete for aboveground engineered disposal facilities using portland cement concrete as the primary construction material.

3.1 Frost Action

The following items compose the recommendations to overcome frost damage.

3.1.1 Design the structure to minimize exposure to moisture. The building geometry must provide good drainage, with no surface that will provide for potential ponding. Therefore, use a sloped roof rather than a flat roof. Floor slabs must have a vapor barrier between the slabs and grade. Unnecessary joints must be eliminated.

3.1.2 Use low water-cement ratio. For structures of this type the water-cement ratio should not exceed 0.50.

3.1.3 Provide air entrainment in the mixture. It is recommended that air-entrained concrete be used for this construction and Table 3 shows the recommended air contents derived from ASTM (1977).

3.1.4 Use only suitable materials.

3.1.4.1 Cement. The several types of portland and blended cements, in properly proportioned and produced air-entrained concrete, will provide for resistance to cyclic freezing. However, to resist severe sulfate attack, Type V is required. Therefore, for this added protection, Type V conforming to ASTM C 150 is recommended.

3.1.4.2 Aggregate. The aggregates used for this construction should be the very best available, as long as it is cost-effective to obtain them. Careful judgement must be used in deciding the cost-effectiveness factors considering the nature of the material to be disposed. The aggregates should be thoroughly characterized by the physical tests required, i.e., petrographic examination, absorption, specific gravity, soundness tests, and determination of pore structure. These tests are described in the Handbook for Concrete and Cement (US Army Engineer Waterways Experiment Station, 1949).

Table 3

Recommended Air Contents for Freeze-Thaw Resistance

Nominal Maximum Aggregate Size mm	(in.)	Air Content, Percent Moderate Exposure	Severe Exposure
9.5	(3/8)	6	7.5
12.5	(1/2)	5.5	7
19.0	(3/4)	5	6
37.5	(1-1/2)	4.5	5.5
75	(3)	3.5	4.5
150	(6)	3	4

3.1.4.3 Admixtures. Air-entraining admixtures should conform to ASTM C 260.

3.1.5 Use proper curing. Proper curing procedures and materials are required for durable concrete; they should comply with ACI Standard 308-81 (ACI, 1981). Depending on the structural member being cured, the techniques of inundation, water spray, wet burlap, plastic membrane, and sprayed-on membrane are recommended. The curing period should be that established in the laboratory which achieves a specified strength with that particular curing technique.

3.1.6 Use sound construction practices. Good construction practices should be implemented to obtain durable concrete. These include proper mixing, placing, handling, and consolidating of the concrete; protection against extreme temperatures; good forming techniques; use of a form material that will give a smooth dense finished surface; proper curing, especially after form removal; and immediate repair of any surface defects.

3.2 Aggressive Chemical Exposure

Protection against sulfates in the soil or groundwater is achieved by the use of sulfate-resistant cement in dense, high quality concrete with a low water-cement ratio. Table 4 provides certain recommendations for sulfate protection taken from ASTM (1977).

Protection against mild acid attack is achieved by the use of a dense concrete with a low water-cement ratio. However, surface coatings or treatments are required to protect against groundwater, soil, or accidental spills containing high concentrations of acids. ACI Committee 515 (ACI, 1974) has recommended certain barrier coatings for concrete under certain conditions. Table 5 gives recommendations for dampproofing coatings and Table 6 gives recommendations for protective barrier systems. Tables 5 and 6 were taken from ACI (1974).

3.3 Abrasion

Abrasion resistant concrete surfaces will be achieved by implementation of the following measures.

3.3.1 Use low water-cement ratio.

3.3.2 Use well-graded, hard, tough fine and coarse aggregates, with a maximum size of 1 in., meeting the requirements of ASTM C 33 (ASTM, 1981).

3.3.3 Use the lowest slump concrete that is practical for the working conditions (maximum 3 in., 1 in. for toppings).

3.3.4 Air content should be consistent with exposure conditions.

3.3.5 Use a topping layer over the main slab if severe wearing conditions are anticipated.

3.3.6 Finish (float and trowel) the surface only after the surface has lost its sheen.

3.3.7 Vacuum dewatering techniques can be used to remove excess water immediately after placing, resulting in a more dense concrete with increased strength and surface enhancement against wear.

3.3.8 Curing techniques of water spray, damp burlap, or cotton mats are recommended and the curing should be for 7 days.

3.4 Reactive Aggregates

3.4.1 Avoid alkali-reactive aggregates. If possible, reactive aggregates should not be used. However, if their use is unavoidable, they should only be used with low-alkali cement (maximum 0.60 percent equivalent Na_2O).

3.4.2 Determine alkali-carbonate reactivity and use measures to reduce the effects of this reaction.

3.4.2.1 Avoid reactive rocks.

3.4.2.2 Dilute the reactive rocks by the inclusion of nonreactive rocks.

3.4.2.3 Use low alkali cement.

3.5 Corrosion of Embedded Materials

The following measures should be employed to protect embedded items from corrosion:

3.5.1 Use low water-cement ratio.

3.5.2 Avoid honeycombing (provide good consolidation).

3.5.3 Use adequate concrete cover.

3.5.4 Design against structural cracks.

3.5.5 Keep chloride content below permissible values.

3.5.6 Provide protective coating on the concrete.

3.5.7 Provide coating on the steel.

3.5.8 Use good curing techniques.

Table 4

Protection of Concrete Subject to Sulfate Attack

Exposure	Sulfate in Water, ppm	Type Cement Required	Recommended Water-Cement Ratio, max.
Severe to very severe	1,500 to 10,000 and greater	Type V	0.45
Mild to moderate	150 to 1,500 IP(MS) IS(MS)	Type II	0.50

Table 5

Recommended Dampproofing Materials and Techniques

Recommended Material or Technique	Siting Condition			
	Above Grade		Covered or Buried	
	Ext. Face	Int. Face	Ext. Face	Int. Face
Portland cement Paint (water based)	X	X	/	X
Asphalt (cold applied)	X	X	X	//
Latex Paint (PVC)	X	X	/	X
Epoxy Paint (two-component)	X	X	/	X
Chlorinated Rubber Paint(solvent based)	X	X	/	X
Polyurethane Paint (moisture-cured or two-component)	X	X	/	X

/Exterior coating also required (see list in this table for other recommended materials).

//Interior coating also recommended (see list in this table for other recommended materials).

Table 6

Protective Barrier Systems in Chemical Environment

	Protection Against	
Exposure	Barrier System	Expected Attack
Severe	Composite system of: (1) Asphalt membrane covered with acid-proof brick and chemical-resistant mortar (greater than 6 mm thick)	Concentrated acid or acid/solvent material
	(2) Epoxy system (sand filled) topped with unfilled pigmented epoxy (0.5 mm to 6.75 mm thick)	Water, dilute acids, strong alkalies, and salt solutions
Severe	Neoprene sheet (precured, PVC sheet (plasticized), glass-reinforced (GR) epoxy, GR polyester (0.5 mm to 6 mm thick)	Organic acids (ph<3), salt solutions, strong alkalies
Moderate	Bituminous materials, sand-filled systems of epoxy, polyester or polyurethane (3 mm to 9 mm thick)	Abrasion and dilute acids (intermittent exposure)
Mild	Asphalt, chlorinated rubber, epoxy, vinyl, polyurethane, neoprene, coal tar, coal tar epoxy, coal tar urethane, styrene-acrylic copolymer, acrylic, polyvinyl butyral	Salts (such as deicing), frost damage, solutions with ph>4

3.6 Covered Versus Aboveground Structure

The recommendations presented so far have been applicable to aboveground structures. However, if a structure is covered, the information in Tables 5 and 6 must be put to use. The details of the materials and practices will be dictated by the characterization of the cover material. All other recommendations, as shown for the aboveground case, are applicable for underground structures.

3.7 Testing of Component Materials and Final Mixture

Once a decision has been made to construct an engineered disposal facility at a particular location, a test program should be designed and specified that will result in the use of the very best materials to produce the most durable concrete possible. The program should be designed so that the carefully selected components are fully characterized after having been thoroughly tested. The concrete composed of these components should also be fully characterized as to its response to the particular environment.

This program should be followed, once construction begins, with a carefully planned program of quality control and quality assurance. This will insure that the proper components will be used to produce a quality product capable of the high level of durability required.

4. Summary and Conclusions

Adherence to the guidelines and recommendations contained and referenced herein, along with good practices of production and construction, will produce a durable concrete capable of long life. The service life will be further enhanced if proper and timely repair and maintenance procedures are employed, should their need arise. There is no mathematical model that can predict service life of a structure, but by producing the best concrete possible and employing the best construction practices, the implication is that the material and structure will function for many years.

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b. PERIOD COVERED (Inclusive dates)

12. SUPPLEMENTARY NOTES

13. ABSTRACT (200 words or less)

The study reported herein contains the results of Task 2c (Technical Requirements for Earth Mounded Concrete Bunker Disposal of Low-Level Radioactive Waste) of a four-task study entitled "Criteria for Evaluating Engineered Facilities." The overall objective of this study is to ensure that the criteria needed to evaluate five alternative low-level radioactive waste (LLW) disposal methods are available potential license applicants. The earth mounded concrete bunker disposal alternative is one of several methods that may be proposed for disposal of low-level radioactive waste. The name of this alternative is descriptive of the disposal method used in France at the Centre de la Manche. Experience gained with this method at the Centre is described, including unit operations and features and components. Some improvements to the French system are recommended herein, including the use of pervious backfill around monoliths and extending the limits of a low permeability surface layer. The applicability of existing criteria developed for near-surface disposal (10 CFR Part 61 Subpart D) to the earth mounded concrete bunker disposal method, as assessed in Task 1, are reassessed herein. With minor qualifications, these criteria were found to be applicable in the reassessment. These conclusions differ slightly from the Task 1 findings.

14. DOCUMENT ANALYSIS a. KEYWORDS/DESCRIPTORS

low-level radioactive waste	evaluation criteria
waste disposal	concrete bunkers
alternative disposal methods	tumuli
engineered disposal	

b. IDENTIFIERS/OPEN-ENDED TERMS

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